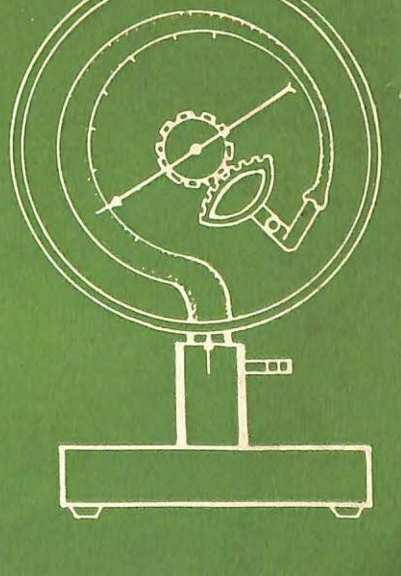
OXFORD MODERN SCIENCE

2

PHYSICS

Maurice Banerjei



OXFORD MODERN SCIENCE

Volume 2

PHYSICS

For Classes 7 & 8

INSTITUTE OF EDUCATION FOR WOMEN.
3392
Deptt of Extension
Services.
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CALCUTTA-27

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Preface

This book presents a two-year course in Physics designed for Classes 7 and 8 of either a Class 10 terminal course, or a Class 11 terminal course.

It introduces the subject in terms of the student's personal experience. A strong foundation of scientific theory is laid, but at every stage theory is related to reality, and the student's natural curiosity is aroused and sustained.

Volume 1 of this series is a book on combined science designed for Class 6. Volume 2 Physics is the first part of a four-year course in Physics, and is followed by Volume 3 which provides a course for Classes 9 and 10. This four-year course has been carefully graded to suit Classes 7, 8, 9 and 10, in content and in the approach to the subject. It is a complete course in Physics for those who end a general education in Class 10, leading to the I.C.S.E. examination, but care has been taken to provide a complete school course that should meet the requirements of any Class 10 terminal examination. This course is also most suitable for those intending to appear for the I.S.C. examination in Physics, as the little that remains to complete that syllabus can be comfortably finished in Class 11, leaving plenty of time for a review of the whole course.

Energy has been presented as a unifying principle. The concepts of energy, matter and force have been very carefully developed along modern lines suggested by recent thinking on the subject of science teaching in schools. The basic ideas of heat, light, sound, magnetism and electricity have been carefully presented and developed. Clear understanding and stimulation of interest are constantly aimed at, and a strong foundation is laid for future work.

The concentric approach has been used. A topic, e.g. the refraction of light, is introduced and left at that — a central dot of knowledge. In succeeding years it is developed further in wider and wider circles, ripples of information and knowledge spreading outward. Terms are first introduced without a formal definition, which at an early stage would serve no useful purpose but would only confuse the student; a newton is a unit of force, temperature is measured with a thermometer, current is measured in amperes on a meter, etc. As the course progresses definitions become more and more evident or are stated explicitly.

Analogies and models are used throughout. These can be dangerous if they are to be considered to be more than illustrations, but they have a valuable place in science teaching.

Questions are frequently asked in the body of the text and a carefully constructed set of questions is given at the end of each chapter. These questions test the student's grasp of the matter covered, but more than that they have been designed to encourage students to read the whole chapter, and to refer to past chapters and perhaps consult other sources as well.

S.I. units have been used throughout the book, and the most recent recommendations for the correct revision of older terminology have been implemented. Thus 'specific heat capacity' is used in place of the older 'specific heat', and the 'joule' has been used together with the 'calorie' as a unit of heat, since it is to replace it as soon as possible.

This book has been produced with the encouragement, cooperation and help of so many people that it would be impossible for me to thank all of them individually or adequately. In particular, I would like to thank Mr. John West, author of the Chemistry books of this series, for many stimulating ideas and suggestions, Mr. K. P. Pradhan for trying out many prototype experiments and for preparing the index, Mr. B. Pradhan, the illustrator, for his great patience and skill in portraying the meaning of the text, and Mr. Chandan Singh Rawat for converting an untidy manuscript into a clear typescript for the printers.

Darjeeling 1973 MAURICE BANERJEI

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Part 1

FOR CLASS 7

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1

Introducing Physics

1. What is Physics?

THE scope of Physics is so wide, and its developments so numerous, that it is difficult to find a single statement that will convey the full meaning of the subject. Physics is a basic science, whose principles form the foundation of other sciences such as biology, chemistry, geology and astronomy. Physics is concerned with the laws that underlie the working of our Universe. Every time you turn on a tap, switch on a light, speak on the telephone, ride in a car, or use one of the many other machines that have become so common in our lives, you are coming into contact with something made possible by a knowledge of physical laws.

Physics is concerned with the way our Universe works. Everything physical in our Universe can be classified as either *matter* or *energy*. Matter can be classified as living or non-living. All the sciences can be divided into two main branches: the *biological* sciences, which deal with living things, and the *physical* sciences, which deal with the non-living aspects of nature. *Physics* may therefore be defined as *the physical science which deals with matter and energy and their transformations.* In the next chapter we shall discuss *energy* more fully, and in the chapter after that we shall study *matter*. However, as you continue your study of Physics, you will learn more and more of these two aspects of the Universe.

2. Why we should study Physics?

We live in this Universe; we are part of it. So we should know what we can of its working to help us live better and fuller lives. Physics deals with the working of our Universe. The study of Physics will make our Universe more meaningful to us and more full of interest and excitement, as we learn the 'why' and the 'how' of it, and see the pattern and power of it.

Science is marching forward at a swift pace. During the last sixty years or so science has progressed more than during all previous time. From the time of the writing of this book till the time you study it, great new discoveries will probably have been made. What happens in the future will affect us, directly or indirectly, either by bringing new inventions for our benefit and use, or dangers for us to avoid. To understand what may come we must learn the laws that will help to explain it, and these are the laws that form the structure and framework of Physics.

Physics has a pattern and an order to it, and its study involves careful observation and correct reasoning – in brief the scientific method. In studying Physics, this scientific training will not only sharpen our observation, develop our powers of reasoning, improve our minds and increase our store of knowledge, but furthermore all these qualities will carry over, or 'transfer', into other areas of work and study, and make us more useful and more productive members of society.

Finally, there is the very interest of the subject itself. The physicist is like a detective. He searches for clues. He rejects what is not useful and concentrates on what will help him, and he uses this evidence to reason further and come to the solution to his problem. It is a hot and exciting chase, full of the thrill of discovery and the joy that is brought by finding the correct answer.

3. The unreliability of our senses in giving accurate information

Physics deals with the working of our Universe, and to study Physics we have to study, to measure, the forms of matter and energy that make up our Universe. We explore our environment, the forms of matter and energy around us, with our senses. But can we rely on our senses to give us accurate information? Let us consider some examples.

(i) Look at each of the following lines and say which is longest and which is the shortest. Now measure each line. (see Fig. 1.1).

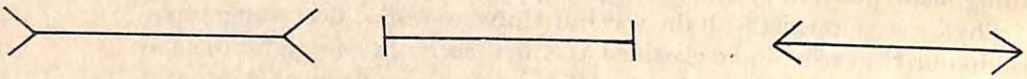

Fig. 1.1 **Optical illusion with lines**

(ii) Are the circles in the centre equal in size? What do these two examples tell you of your eye as a judge of size? (see Fig. 1.2).

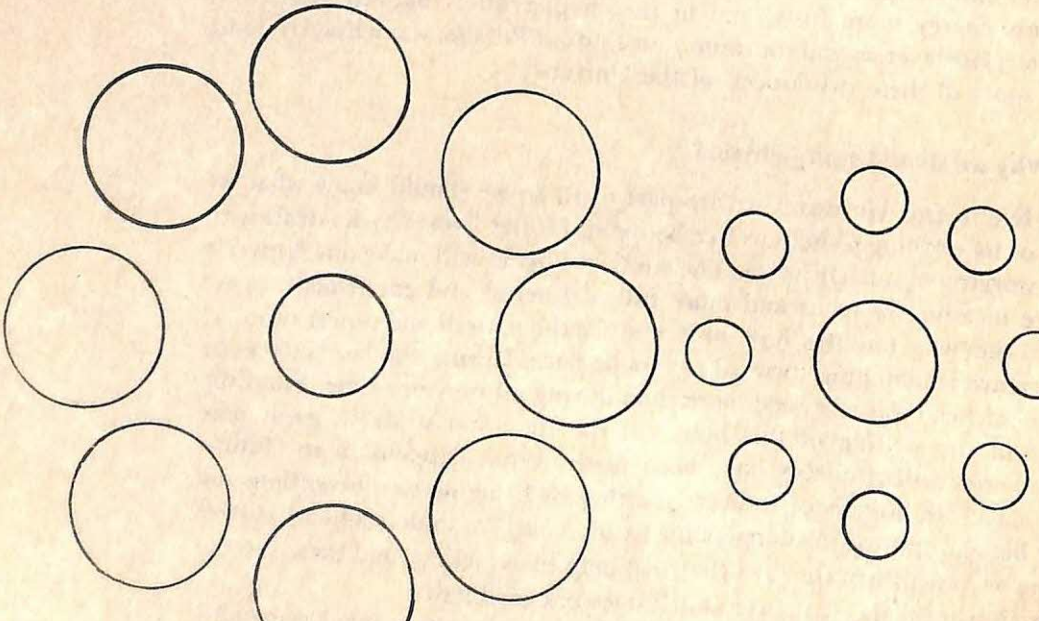

Fig. 1.2 **Optical illusion with circles**

(iii) You are asked to determine the temperature of some water in a bowl B. There is a bowl A of very hot water on the left hand side of this bowl, and a bowl C of ice-cold water on the right hand side of it. If you plunge your hand in A and then in B, it will feel colder than it really is. If you plunge your hand first in C and then in B, it will feel warmer than it really is (see Fig. 1.3). What does this tell you about your sense of feeling as a temperature measurer?

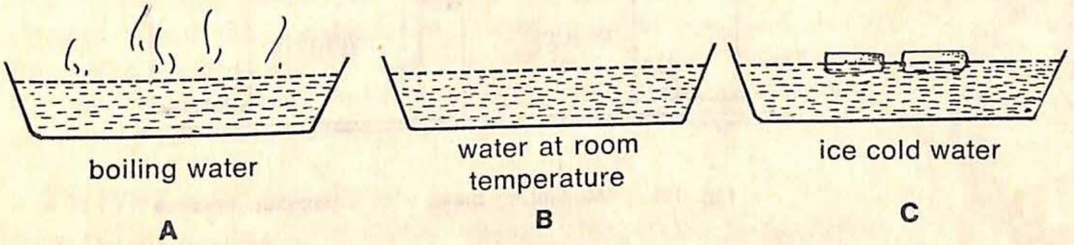

Fig. 1.3 **Three bowls with water at different temperatures**

From these, and other examples, we see that our senses are affected by particular circumstances, or in other words are *subjective*, and therefore not to be always relied on to give accurate information. We must therefore use something less personal, less subjective. We use instruments to get objective and exact measurements in Physics.

4. Some of the instruments with which we measure the physical world

Most of our measurements concern length, mass and weight, and time. Fig. 1.4 shows a block being measured with a metre stick. We shall measure lengths in metres if they are large and in centimetres if they are small. It is important when taking any scale reading to have the correct line of sight.

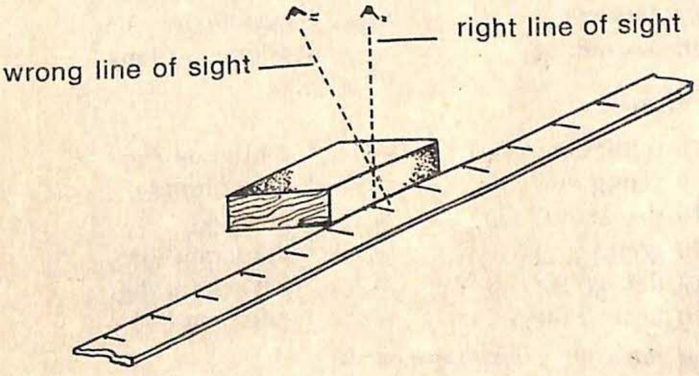

Fig. 1.4 **Block being measured with a metre stick**

Fig. 1.5 shows the common balance with which we find the mass of an object placed in the left hand pan, by placing a mass in the right hand pan which will be affected exactly the same by the pull of gravity. The mass of iron being measured is 30.15 g. We shall measure mass in kilograms if it is large and in grams if it is small.

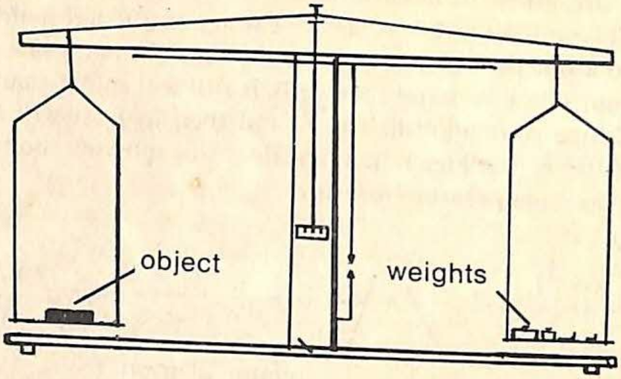

Fig. 1.5 **Measuring mass with a common balance**

Fig. 1.6 shows a spring balance which measures the weight of a body, which is the force with which the earth pulls that body towards it. The weight of the piece of metal being weighed is 1 100 g. We shall for the present measure weight in the same units as mass viz. kilograms, grams, etc. but we must remember that mass and weight are not the same, although they are related to each other. This relationship will be discussed further in Chapter 4.

At this stage we shall give the units of length and mass and their subdivisions.

Units of Length

10 millimetres (mm) = 1 centimetre (cm)
10 centimetres = 1 decimetre (dm)
10 decimetres = 1 metre (m)
10 metres = 1 dekametre (dam)
10 dekametres = 1 hectometre (hm)
10 hectometres = 1 kilometre (km).

Units of Mass

10 milligrams (mg) = 1 centigram (cg)
10 centigrams = 1 decigram (dg)
10 decigrams = 1 gram (g)
10 grams = 1 dekagram (dag)
10 dekagrams = 1 hectogram (hg)
10 hectograms = 1 kilogram (kg)

(Note that the same prefixes are used.)

Latin

milli $= \frac{1}{1000}$
centi $= \frac{1}{100}$
deci $= \frac{1}{10}$

Greek

deka = 10
hecto = 100
kilo = 1000

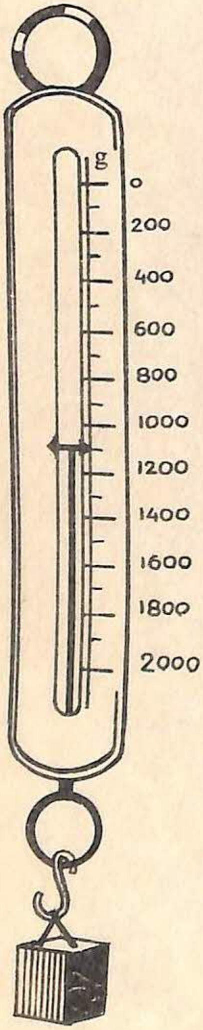

Fig. 1.6 **Measuring weight with a spring balance**

How many millimetres are there in a centimetre? in a metre? How many centimetres are there in a metre? How many metres are there in a kilometre? How many g are there in a kg? How many mg in a g? How many cg in a g?

Fig. 1.7 shows a stopwatch, which measures time as an ordinary watch does, but which can be started and stopped at will to enable us to measure time more accurately and more conveniently.

Two other instruments used for measuring which we shall have something to do with this year are the thermometer, shown in Fig. 1.8, and the barometer, shown in Fig. 1.9. The thermometer is used for measuring the temperature of an object, and the barometer measures the pressure of the air at any place at any instant of time.

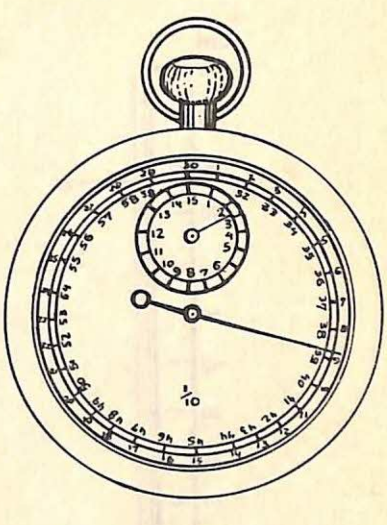

Fig. 1.7 **A Stopwatch**

5. The Work of the Physicist

Since Physics is the study of matter and energy and their transformations, this is what the physicist must study. But this is a very wide area and, generally, a particular physicist concentrates upon a particular area and devotes his time and energy, sometimes his entire life, to the study of only this area so that he can study it in great detail. Thus Physics has been divided up into smaller areas, like Mechanics, Wave Motion (Sound, Light), Heat, Electricity and Magnetism, and Modern Developments in Physics which include Electronics and Nuclear Physics. All these names will mean more and more as you study more Physics and learn more about each of these sections.

In general terms the work of the physicist is to observe changes in matter and energy that take place either in the Universe, or in his laboratory where he has deliberately caused these changes to take place so that he may study them. He observes closely, very often with the aid of complicated instruments, and measures accurately. He draws conclusions from his observations and measurements, and uses these conclusions to state broad facts, or laws, about the physical world. The applications of these laws bring the machines, and labour-saving and pleasure-giving devices, that make life easier and happier, and also quite often the cure to ills that were once a curse to mankind.

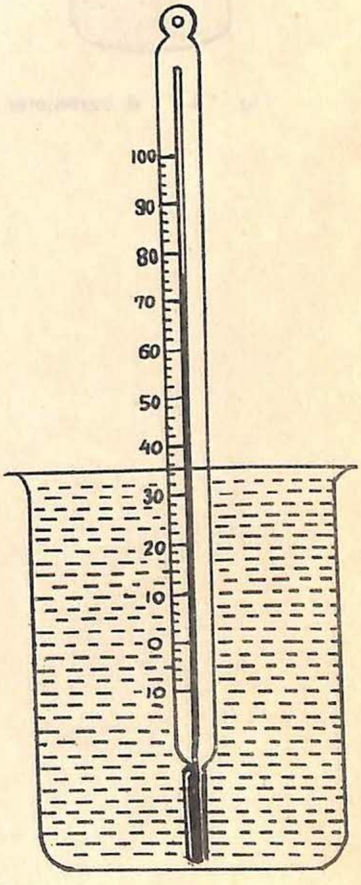

Fig. 1.8 **A thermometer**

6. Some famous physicists

There have been so many whose dedicated work has built the vast and complicated structure of Physics, that to name them all would take more than one book. So we shall just mention a few of the very important physicists, and some of their work, and while doing so we must bear in mind that there are many whose names are not mentioned here, but whose contribution to Physics should never be considered unimportant.

Dr William Gilbert (1540-1603) carried out many interesting experiments in magnetism and static electricity.

Galileo (1564-1642) was a famous Italian physicist, astronomer and mathematician.

Sir Isaac Newton (1642-1727) an English mathematician and physicist, who made a number of important discoveries and is one of the greatest names in Physics and Mathematics.

Albert Einstein (1879-1955), a German physicist who later settled in America, is best known for his famous Theory of Relativity.

The work of Ampere, Volta, Ohm and Faraday in electricity was so important that their names are still used to name various fundamental electrical units.

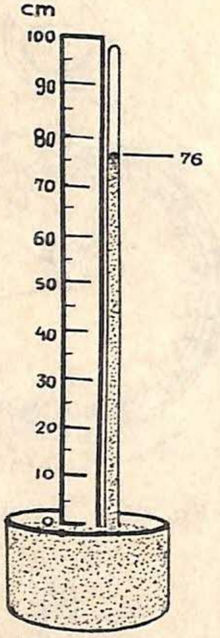

Fig. 1.9 **A barometer**

More recently the work of Rutherford, Bohr, and others on the atom, Becquerel and the Curies in radioactivity, and Chadwick in discovering the neutron are all milestones in the great journey forward, and in which so many others have had a share. The important point is that science is cumulative. That which was discovered and known in the past, assists in future discoveries. It is this that Newton had in mind when he said 'If I have seen farther than most men, it is because I have stood on the shoulders of giants'.

In conclusion we shall mention some of our famous Indian physicists, whose work and whose contribution to mankind through their work should be a source of inspiration to all of us.

Professor Meghnad Saha (1893-1956) established a school for research in astrophysics at Allahabad. His theory of Thermal Ionisation was acclaimed throughout the world as a major discovery. He founded the Institute of Nuclear Physics at Calcutta, and this institute is now named after him. He started the journal 'Science and Culture', and took a prominent part in National Planning.

Dr Homi Jehangir Bhabha (1909-1966), after taking an Engineering degree at Cambridge University, returned to India in 1940 and was a Reader and then a Professor at the Indian Institute of Science, Bangalore. In 1945, he founded the Tata Institute of Fundamental Research at Bombay, and later he established the Atomic (nuclear) Research Centre at Trombay, which is now named after him. His death in an air crash deprived India of an eminent atomic scientist.

Professor C. V. Raman (1888-1970) started his career as an officer in the Indian Finance Department but soon resigned from government service because of his interest in Physics, and joined the University of Calcutta as a Professor of Physics. He carried on his research work in Physics with great enthusiasm and made a great discovery known as the *Raman Effect* for which he was awarded the Nobel Prize for Physics in 1930, the highest world recognition given to a scientist. He established his own Institute at Bangalore in 1948, and devoted his life to research in Physics.

The purpose of this chapter is to tell you something about Physics and the work of physicists, and to explain to you why you should study Physics; to explain to you that measurement is an important part of the study of Physics and that our senses are not to be relied upon to give accurate information and that we need instruments for this. Finally the units of length and mass were given so that their sub-divisions can be learnt from the very beginning.

We are now at the start of a long and interesting journey. This chapter has given you an idea of what lies ahead, what you should look for, what the journey will be like, and of some of the many who have made this journey possible for you.

Questions

1 Name six different objects or machines which are applications of physical principles.

2 Give three compelling reasons why we should study Physics.

3 Give two examples, one concerning touch and one concerning sight, to show that we cannot rely on our senses to give accurate information.

4 Briefly describe the work of the physicist.

5 Give the names of six famous physicists, and name one discovery made by each of any three of them.

2
Energy

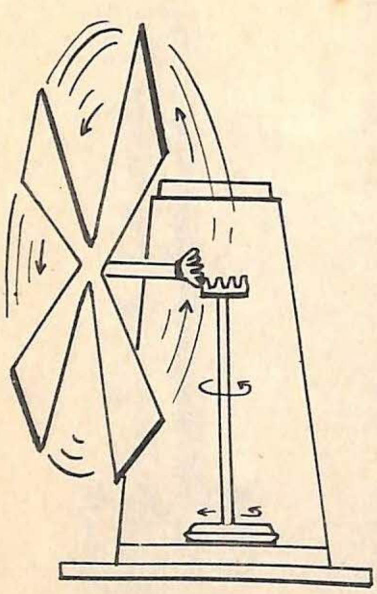

Fig. 2.1 **Sails of a windmill turning in breeze**

Our universe is never still. Things are always happening. There is movement and change going on all the while, all around us. To do the work of bringing about these changes and these movements, energy is needed. *Energy can be described as the capacity to do work, or to bring about some effect or change.*

The wide variety of changes going on, and the multiplicity of results, arising from these changes, constitute the pattern of our day to day living. Such a wide variety of changes and results need to be activated by a correspondingly wide variety of energy forms. The evaporation of water and its subsequent falling as rain involves one form of energy; the miracle of photosynthesis, or the digestion of food involves quite a different form of energy, and the glowing of an electric fire yet a different form of energy.

It will be our work in this chapter to study some of the different forms of energy, and how they produce some of the changes that are constantly going on around us, and which we describe in general terms as the working of our universe.

1. Some of the different forms of energy

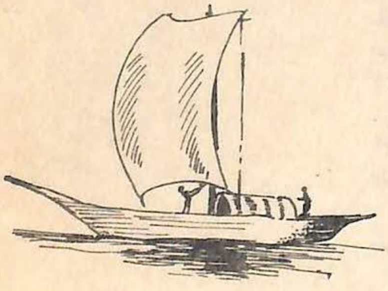

Fig. 2.2 **Wind moving a sailboat**

Wind, which is air in motion, can turn the sails of a windmill (see Fig. 2.1) or can push against the sails of a boat and move it forward along the surface of water (see Fig. 2.2). Water in motion can turn the paddles of a water-wheel (Fig. 2.3). A moving stone can shatter a pane of glass. A moving bullet can force its way through a solid such as wood. All these are able to do the work described because of the energy they have due to their movement. *Energy of movement is called kinetic energy.*

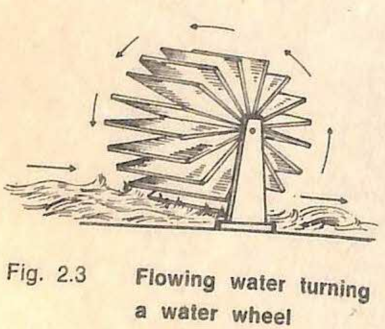

Fig. 2.3 **Flowing water turning a water wheel**

A stone at the top of a building can, when it falls, bring about many effects like breaking a sheet of glass, burying a peg into the ground (see Fig. 2.4), or lifting a weight (Fig. 2.5). All these effects require energy to make them happen. The stone has this energy because of its position at the top of the building. Similarly, water at a height has energy, and in falling can do useful work, like turning a wheel (Fig. 2.6) which in turn can be used to work machinery. *Energy due to position is called potential energy.* The word 'potential' means 'possible', and *potential energy* is possible energy, or in other words *stored energy*. A body can have this energy stored in it in various ways. Height is one way. Here are some other ways. A compressed spring in trying to release itself can do work (see Fig. 2.7); the act of compressing it stores energy in it. A stretched rubber band can do work in restoring itself to its original state (see Fig. 2.8); the act of stretching it stores energy in it. Both the compressed spring, and the stretched rubber band, have potential energy.

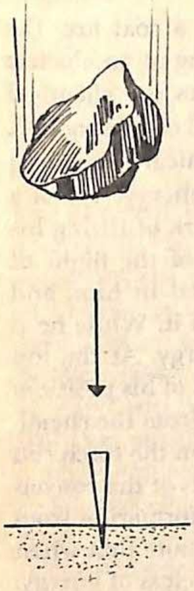
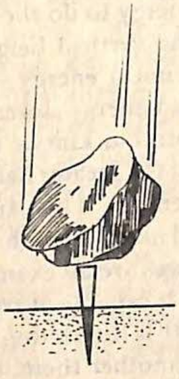

Fig. 2.4 **A falling stone burying a peg**

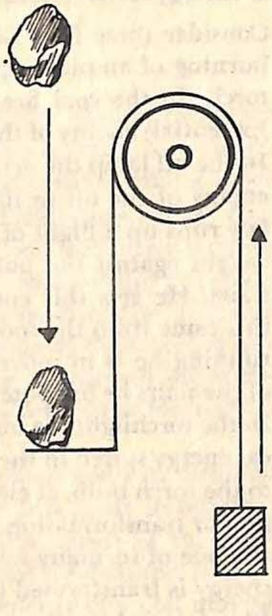

Fig. 2.5 **A falling stone lifting a weight**

Wood, coal, oil and gas have energy stored in them. This stored energy is potential energy, but this form of potential energy is more correctly described as *chemical energy*. The chemical (potential) energy of wood, coal, oil, and gas can be released by burning the substance, and can then be made to do useful work such as warming a house, cooking food, producing light, or driving machinery. Green plants can perform photosynthesis, the amazing chemical reaction by which they can store the energy of the Sun as chemical energy in the carbohydrates produced by the reaction. The food we eat has stored energy, or potential energy stored as chemical energy, and this is the energy with which our bodies do all the work our day to day living involves.

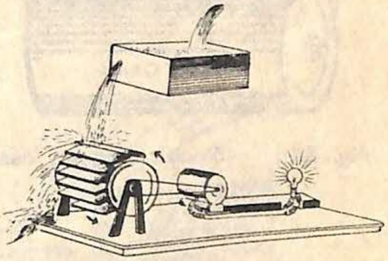

Fig. 2.6 **Falling water turning a paddlewheel**

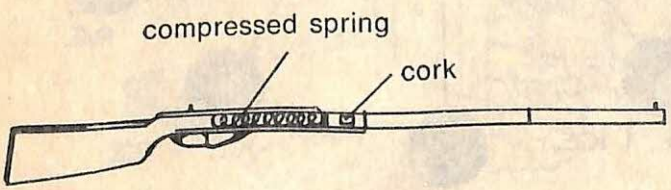

Fig. 2.7 **A toy 'pop'-gun**

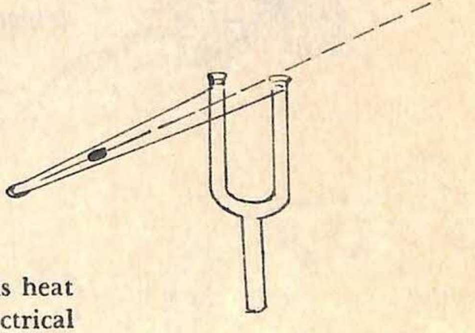

Fig. 2.8 **A rubber catapult**

The energy released when we burn coal or oil or wood or gas is heat energy and light energy, and sometimes even sound energy. Electrical energy from a torch cell can heat a wire (see Fig. 2.9), or light a bulb (Fig. 2.10). Magnetic energy can attract an iron nail from a distance.

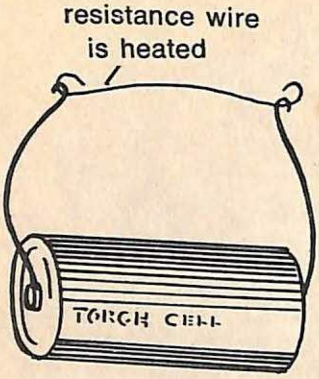

Fig. 2.9 **Electrical energy can heat a wire**

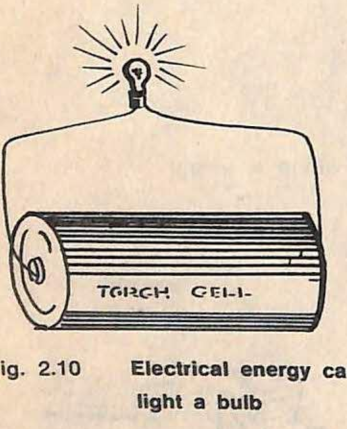

Fig. 2.10 **Electrical energy can light a bulb**

We shall talk about all these forms of energy throughout this book. In fact the study of Physics, as we said earlier, involves the study of energy.

2. Energy Conversions

Consider these four familiar happenings: the burning of a coal fire, the burning of an oil lamp, a boy running upstairs, the glowing of an electric torch. In the coal fire the act of burning the coal changes the chemical (potential) energy of the coal to heat energy with which food can be cooked. In the oil lamp the act of burning the oil converts the chemical (potential) energy of the oil to light energy and also partly to heat energy. When a boy runs up a flight of stairs, he needs energy to do the work of lifting his weight against the pull of gravity up the vertical height of the flight of stairs. He gets this energy from the chemical energy stored in him, and this came from the food he ate, which had energy stored in it. While he is running he is in movement and therefore has kinetic energy. At the top of the stairs he has potential energy due to the greater height of his position. In the torchlight the bulb gives out light energy. This came from the chemical energy stored in the cell, which moved along its path from the torch cell to the torch bulb, as electrical energy. These are all examples of the conversion or transformation of energy. Energy is capable of transformation from any one of its many forms to any other. It is interesting to note that when energy is transformed from one form to another there is no loss of energy. This fact is known as the *conservation of energy*.

Consider the energy changes in the following case. A metal weight (see Fig. 2.11) hangs from a nail by a string. It is drawn up on one side and released. Will it swing forever? If not, what happens to its energy which according to the conservation of energy is not lost during conversion from one form to another? Would it swing forever in a vacuum? Would the string and nail have to be frictionless? Does the air get heated in the case described?

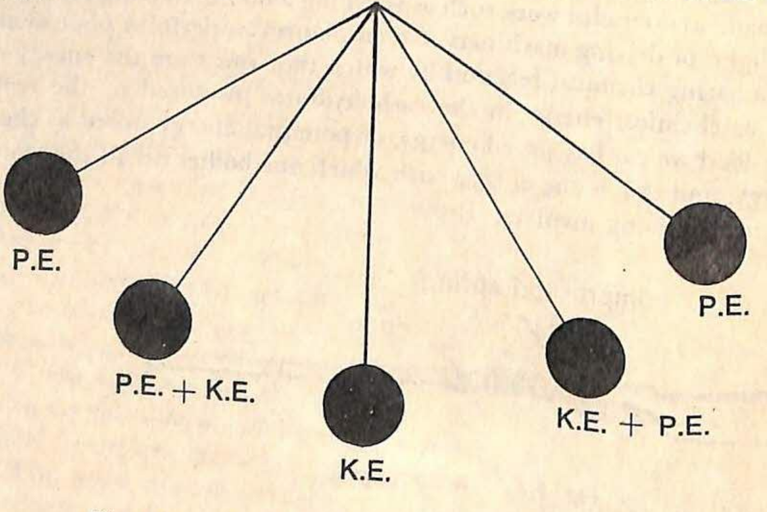

Fig. 2.11 **Energy changes in a swinging pendulum**

Trace the energy changes that occur when a small boy winds up a toy motor car and releases it on the ground. What energy does he spend? Where does he get it from? In what form is this energy stored in the spring of the car? With what energy does the car move? Are any other forms of energy released during the entire process? If so, what are they and when are they released?

3. Energy converters in action

The coal fire, the oil lamp, the running boy, and the electric torch are all energy converters since they convert energy from one form to another. All around us, and even within us, change and movement is taking place and these all involve energy conversions. So there are many energy converters in the Universe, including our own bodies, and their actions constitute the working of the Universe, and are therefore a subject of study in Physics. A weight swinging to and fro, which is described as a simple pendulum, is an energy converter no less than the body of the running boy or the electric torch. Our work in Physics will take us through the study of many energy converters. We shall mention only a few of the more familiar ones at this stage.

Have you ever thought of where the electricity which you can summon to your service at the press of a button comes from? It is made in different ways. In an electric torch it comes from the chemical nature of the torch cell, but on a large scale it is made by a machine called a *generator*. A generator is an energy converter, changing the kinetic energy of a coil moving between magnets into electrical energy. The coil can be made to move in a variety of ways. One way is with the energy produced by burning diesel oil. In places where moving or falling water is available, this natural energy can be utilised to work the generator, and the process (shown in Fig. 2.12) is known as *hydro-electrification*. The electrical energy produced can be used to work electric lights, fans, heaters, irons, toasters and other electrical gadgets. At every stage you will see an energy converter in action.

Fig. 2.12 **Hydro-electrification**

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A car engine is an energy converter. What is the source of the energy? Is there any evidence of burning? Trace the energy conversions from the time the car engine starts till it stops, the car having travelled along a level road and then up a hill.

An electric train carrying hundreds of people from the suburbs to the city where they work or go to school, is an energy converter. What energy is being converted? From where does it come? To what forms of energy is it converted?

The Sun brings about many energy conversions. It causes vast amounts of water to be evaporated, carried great distances through the air, and later released to fall as rain. Can you trace the energy conversions in this constant evaporation—condensation—precipitation process which is of such great importances in our lives, and which we describe as rainfall? Can you think of any other energy conversions the Sun is responsible for? What about photosynthesis? How did coal and petrol get their energy?

We could go on and on dealing with energy converters, and we will do so right through our study of Physics. It is a most interesting and absorbing study, and a very important one, because it concerns the working of the Universe, and therefore our very own lives, as we are a part of our Universe, and have to depend on the other parts of our Universe.

4. Energy and living things

All living things are made up of protoplasm. Just as a building is made of bricks, our bodies are made up of cells, and the cells are made up of protoplasm. However, unlike the bricks of a building, the cells of our bodies are never at rest. They are in constant movement, as they carry on with their various duties. They need a constant supply of energy for their movements and their work. This energy comes from the food we eat. In addition to this, food is also required to make more protoplasm which is necessary for the repair of damaged cells, or for the replacement of worn out parts, or for growth. All living things need energy, and this energy comes from the food they consume. The food we eat is stored up within us, after the process of digestion, in the form of *sugars*. These sugars give off the energy we require when they are *oxidised* which means converted by combination with the oxygen of the air we breathe in. Just as coal is burnt in the oxygen of the air to carbon dioxide and heat energy, these sugars combine with the oxygen we breathe in to give off heat energy, carbon dioxide and moisture. The heat energy given off by different foods varies, some foods producing a greater proportion of heat energy, weight for weight, than others. The heat energy given off by different foods, or the heat value of different foods as it is called, is measured in *kilogram-calories*, which are also called *Calories* (spelt with a large 'C'). A 'kilogram-calorie' or 'Calorie' is the amount of heat required to raise the temperature of one kilogram of water through 1°C. There is also the *calorie* (spelt with a small 'c') which is the amount of heat required to raise the temperature of one gram of water through 1°C. Thus we see that 1 Calorie or kilogram-calorie = 1 000 calories.

The actual measuring of the heating effect, or *calorific value*, of a substance such as a fuel (like coal or oil) or a food is a difficult process. It is done in a special apparatus, called a *fuel calorimeter* sometimes also called a *bomb calorimeter*, (see Fig. 11.3, p 121) which consists of a large container constructed so as to prevent loss of heat from its interior. Inside this container is a smaller one which holds one kilogram of water. A third, still smaller container is suspended in the water. One gram of the material to be tested e.g. coal, oil, chocolate, is burned inside the smallest container. The heat energy given off as the material burns raises the temperature of the surrounding water. The increase in temperature of this water is measured with a thermometer. The calorific value of the material burned is determined from the increase in temperature of the kilogram of water. For example if its temperature is increased by 1°C, then the calorific value of the fuel or food is 1 Calorie per gram, if its temperature is increased by 2°C, then the calorific value is 2 Calories per gram, etc.

It is quite clear from what has been said above that our bodies are energy-converters of the food we eat, and that the fuel calorimeter is also an energy-converter, imitating the action of our bodies on the food whose calorific value is being measured.

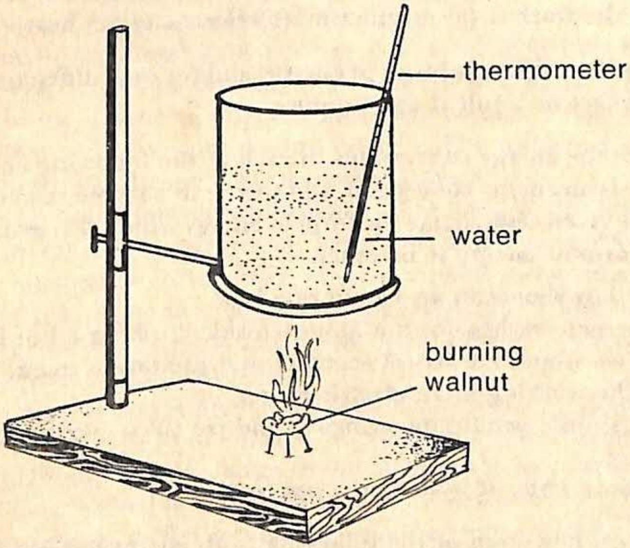


Fig. 2.13 **Heat from a burning walnut**

You can carry out yourself a simple experiment to show the change of food energy to heat. Get a small tin can or a glass beaker. Place half of a cup of water in the can or beaker. By weighing the can or beaker empty, and again with the water, you can find the weight of the water. It would be about 100 g. Place a thermometer in the water. Set up a shelled walnut, having weighed it, under the can or beaker as shown in Fig. 2.13. Support the walnut on straight pins. Take the temperature of the water. Light the walnut with a match. The oils in the nut will burn easily. Watch the thermometer. Note the rise in temperature of the water. Can you calculate the calorific value of walnut from the weight of the walnut burnt, the weight of the water taken and its rise in temperature? Will our answer be very accurate? What main precaution have we not taken, which the fuel or bomb calorimeter is carefully designed to take?

Questions

1 In each case select the answer that best completes each statement.

(i) The ability to do work is (*a*) energy, (*b*) heat, (*c*) chemical change, (*d*) height.

(ii) In a torchlight cell the electrical energy is obtained from (*a*) work, (*b*) chemical energy, (*c*) magnetic energy, (*d*) heat.

(iii) When human beings do work, the energy comes from (*a*) electricity, (*b*) machines, (*c*) from their hands, (*d*) from the food they have eaten.

(iv) Burning is a process in which the burning substance combines with (*a*) energy, (*b*) oxygen, (*c*) carbon dioxide, (*d*) heat.

(v) In engines such as car engines, jets and rockets, the energy which does the work is (*a*) magnetism, (*b*) electricity, (*c*) heat, (*d*) air.

2 Name five different forms of energy, and for each different form state one effect or result it can produce.

3 Trace the energy conversions in each of the following i.e. whenever there is an energy conversion, and there can be more than one in each of the given cases, name the form of energy which changed, and name the form of energy it becomes.

a A boy shoots an arrow out of a bow.
b A rock crashes down a mountainside crushing a hut below.
c Two stones are struck together and produce a spark.
d The working of an electric heater.
e A simple pendulum swings to and fro till it eventually comes to rest.
f Some water is boiled on a gas cooker.

4 Explain how each of the following is an energy-converter.

a the human body,
b the engine of a motor car,
c a green plant,
d a coal fire.

5 Describe three energy conversions brought about by the Sun.

6 Give two of the reasons why a living being requires food. Describe briefly how the heat value of a food is found by experiment. In what unit is it measured? Define this unit.

3
Matter

HAVING studied energy in the last chapter, we now turn our attention to the other aspect of our Universe, *matter*, which *is anything that has weight and occupies space.*

1. Evidence for the fine division of matter

I can get large lumps of sugar and smaller ones. How big is the smallest grain of sugar I could ever get? If I had a very sharp knife and a very powerful microscope and kept cutting a piece of lead into smaller and smaller pieces, could I go on and on forever cutting the lead into smaller pieces, or would I have to stop at some stage because I had come to the smallest piece and could not go any further? The following experiments will help us to find the answers to these questions.

Look at a photograph in a newspaper. The light and dark parts seem to blend smoothly into each other. Now look at it through a magnifying glass or a microscope. Notice that what appeared to be smooth and uninterrupted shading now presents the appearance of a number of grains or particles, the darker parts having more of these to a given space than the lighter parts of the photograph.

Look at some grains of finely powdered chalk under a microscope. Now mix some of this powdered chalk with water, and filter the mixture. The water goes through the fine holes in the filter paper, but the chalk cannot. If both of these are made up of small particles, what does this tell us about the size of water particles compared with the chalk particles?

Blow up two identical balloons, one with your own breath, and the other with hydrogen gas from a Kipp's Apparatus – your teacher will show you how to do this. Seal the necks tightly and see which balloon goes down in size quicker. Try a balloon filled with water also. A particle of air must be very small if it is able to get through the rubber skin of a balloon, and hydrogen gas particles must be even smaller because the hydrogen-filled balloon goes down first. Also the gas particles must be moving, otherwise they would not have pushed their way through the skin of the balloon. Note that the water particles did not move through the skin of the balloon. Does this mean that the water particles are not moving?

Gold can be beaten thinner and thinner until it becomes so thin that we cannot handle it with the fingers. Fine working with this, like putting it on to glass in the form of letters, is done by breathing gently on the very thin gold foil and so moving it into place. Hold a very thin gold leaf between two microscope slides up to the light and you will find that you can see through it. Light cannot pass through a thicker section of gold. Why does it pass through the thinner section?

One gram of potassium permanganate crystals is dissolved in 1 000 cm^3 of water, and we get a pink coloured solution. 1 cm^3 of this solution is removed and put in 1 000 cm^3 of pure water contained in another beaker. We get a more dilute pink solution, and 1 cm^3 of this is removed and put in 1 000 cm^3 of pure water contained in yet another beaker. Can you still detect the pink colour? If I remove 1 cm^3 of this last solution what fraction of the original 1 gram will it contain? If you have worked it out correctly your answer should be $\frac{1}{1\,000\,000\,000}$ or .000000001 gram. Clearly we could continue with the process, putting this 1 cm^3 into another 1 000 cm^3 of water and so on.

By now you should have formed the idea that we can divide matter into very small particles. Let us now make a few more experiments.

If we were to put a large pile of small marbles or lead shot in a large flat tray and shake it, what would happen? How many layers of marbles or lead shot would we get? Now, if a drop of oil is considered to be a collection of particles, just as the large pile of marbles is a collection of marbles, and if a drop of oil is placed on the surface of water, to what thickness would it spread? Clearly from what we saw in the case of the marbles, the oil drop should spread outwards on the surface of the water till its surface area was as large as possible and its thickness was as small as possible, i.e. the thickness of the smallest particles which make up the oil drop.

Fill a beaker to the brim with water and add salt. Does the water level overflow? Now fill a beaker with small marbles and add fine dry sand, gently shaking the beaker. Does the beaker overflow with sand? You will now realise that the water did not overflow in the first case because the salt only filled up the empty spaces between the water particles, just as the sand filled up the empty spaces between the marbles.

If we mix 50 cm^3 of water with 50 cm^3 of alcohol, we would expect to get a total volume of 100 cm^3 of the mixture, but we find in fact that the total volume is less than 100 cm^3. The most reasonable explanation of this decrease in the expected volume would be that each liquid is composed of particles, and that particles of one liquid fill in empty spaces between particles of the other liquid. This is like mixing equal volumes of marbles and lead shot and getting less total volume than the two make separately. It must be that some empty spaces exist in the water and alcohol, and this could only be if each consisted of particles.

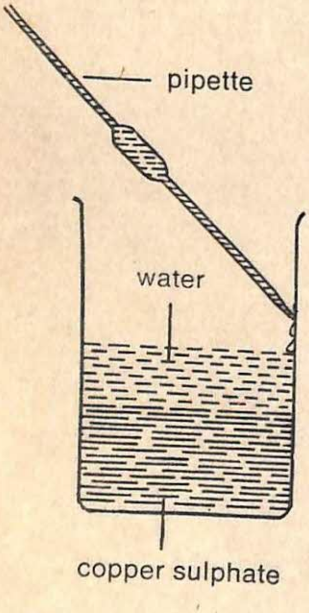


Fig. 3.1 **Adding water above copper sulphate with pipette**

Stand at one end of the room while someone sprays a small amount of perfume into the air at the other end. How long does it take before you smell the perfume? How did it reach you? This not only tells us that the perfume vapour was made up of particles, it also tells us that these particles are moving. Let us see if this happens in a liquid. Put some copper sulphate solution at the bottom of a glass jar. Carefully add water so that it forms a layer on top of the copper sulphate solution without disturbing it. This can be done with a pipette as shown in Fig. 3.1. How long does it take before the two liquids mix completely? What does this tell us about how fast the particles move in a liquid as compared to their rate of movement in a gas? You must also realise that the perfume vapour particles had a longer distance to travel. The movement of the particles of one substance through the particles of another substance, like the particles of perfume moving through the particles of air, is due to the movement of both types of particles. The particles of air, which are also moving, helped to speed the particles of perfume on their way by bumping them along. The particles of water and the particles of copper sulphate solution in the next experiment bumped each other about until both were evenly spread throughout the mixture. This process is known as *diffusion*. It is clearly more pronounced in gases than in liquids. How strong do you think it would be in solids?

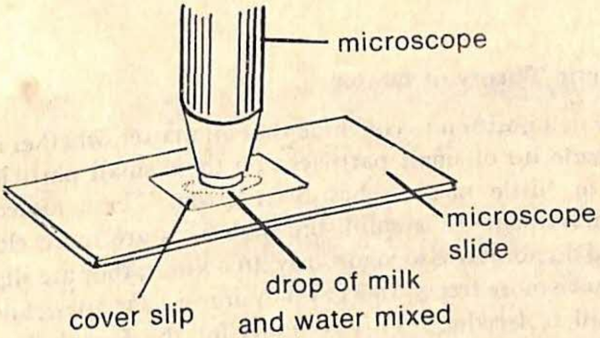


Fig. 3.2 **Observing Brownian motion in a liquid**

One final bit of conclusive evidence about the particle nature of matter is what is referred to as *Brownian Motion*. To show that particles are actually in motion study the behaviour of particles of fat and protein in water, by mixing milk (which consists of particles of fat and protein in water) and water in equal volumes and examining one drop of this mixture under a microscope (see Fig. 3.2). The particles of fat and protein are seen to be pushed this way and that, and this could only be by the smaller particles of the water. It is interesting to see the difference in speed of the particles, the lighter ones being pushed more strongly than the heavier ones. This movement was first discovered by Robert Brown, a Scottish botanist, in 1827 and so it is called Brownian Movement or Brownian Motion. Brown died without ever knowing the real cause of what he had discovered, and it was a long while before the full implications of his discovery were realised. Brownian motion is definite evidence of the particle nature of matter. We can demonstrate Brownian motion in gases by filling a glass tube with smoke and examining, under a miscroscope, how the smoke particles are pushed about by the air particles (see Fig. 3.3).

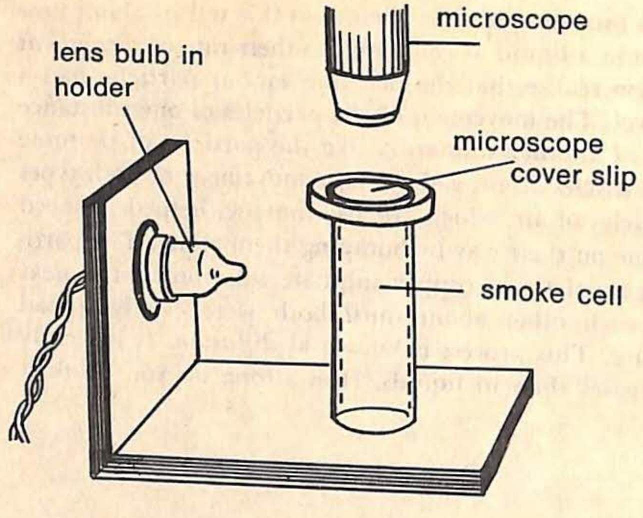


Fig. 3.3 **Observing Brownian motion in a smoke cell**

2. The Kinetic Theory of matter

We are now in a position to conclude that all matter, whether solid, liquid, or gas, is made up of small particles. To these small particles the name *molecules*, or 'little masses', has been given. These molecules are in a state of movement. In a solid, the molecules are more closely packed together and do not move so vigorously. In a liquid they are slightly farther apart and move more freely. In a gas they are very far apart, and move with almost complete freedom. This accounts for the fact that a solid has a definite volume and a definite shape, a liquid has a definite volume but no definite shape and takes the shape of its container, while a gas has neither a definite volume nor a definite shape but diffuses outward in all directions until it is stopped by the walls of some container.

In the last chapter we saw that energy is needed for movement, and that energy of movement is known as kinetic energy. Since the molecules of matter are in a constant state of movement, as was demonstrated in section 1, these molecules must have kinetic energy, and so this theory is known as the *kinetic theory of matter*.

We shall now consider what happens when heat energy is applied to a body. This heat energy is converted by the body to greater kinetic energy of its molecules. The faster rate of movement of the particles creates the higher temperature of the body. Thus the heat condition of a body is a result of the kinetic energy of its particles. *The sum total of the kinetic energy of all the particles is the heat energy possessed by the body*, while *the average kinetic energy of the particles is the temperature of the body.* Thus a red hot nail is at a higher temperature than a large tub of lukewarm water because the average kinetic energy of its particles is much higher, but it has less heat energy than the water in the tub because the number of particles in it is much less, and so the total kinetic energy of all the particles in the nail is less than the total kinetic energy of all the particles in the tub of water. Similarly, a spoonful of water taken from the tub of lukewarm water, before it is allowed to cool, will be at the same temperature as the rest of the water in the tub, but will have less heat energy than it because of its smaller number of particles.

When heat energy is applied to a body, its particles vibrate more vigorously with the increased kinetic energy, and they vibrate through a correspondingly greater distance, which means that the volume of the body increases, or, in other words, it expands. Now, molecules are fairly close together in solids and liquids and much farther apart in gases, and they vibrate far more freely in gases than in solids and liquids, although slightly more freely in liquids than in solids. This means that the expansion of solids and liquids will be fairly similar to each other, but quite different from the expansion of gases which is considerably greater for any given volume.

3. Applications of expansion

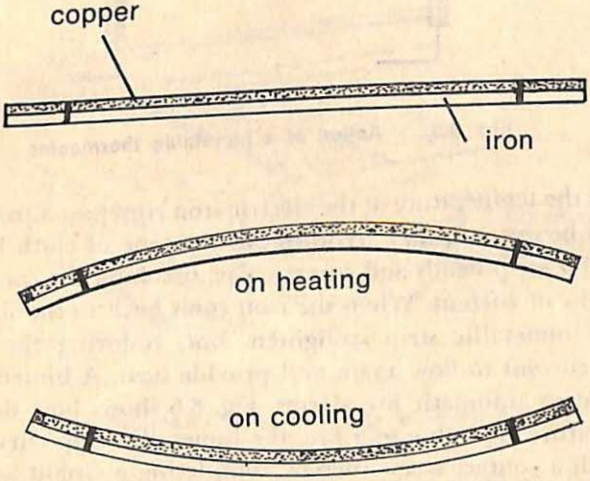


Fig. 3.4 **Curving of a bimetallic strip**

Consider a bar of copper riveted to a bar of iron as shown in Fig. 3.4. A length of copper will expand or contract more than an equal length of iron for an equal rise or fall in temperature. This means that this compound bar will curve with copper on the outside when heated, and with iron on the outside when cooled. The curving of bimetallic strips is put to use in *thermostats*, which are arrangements for keeping the temperature produced by any heating arrangement steady at a given value. For example, the temperature of an electric iron that has been plugged in would rise higher and higher, and the iron would burn the cloth unless the plug is pulled out to stop the heating. Then the iron soon gets cold and the plug must be put in again. This can be done automatically, which saves the bother of putting the plug in and taking it out repeatedly, by using a bimetallic strip in the electrical connections inside the iron. Its action is shown in

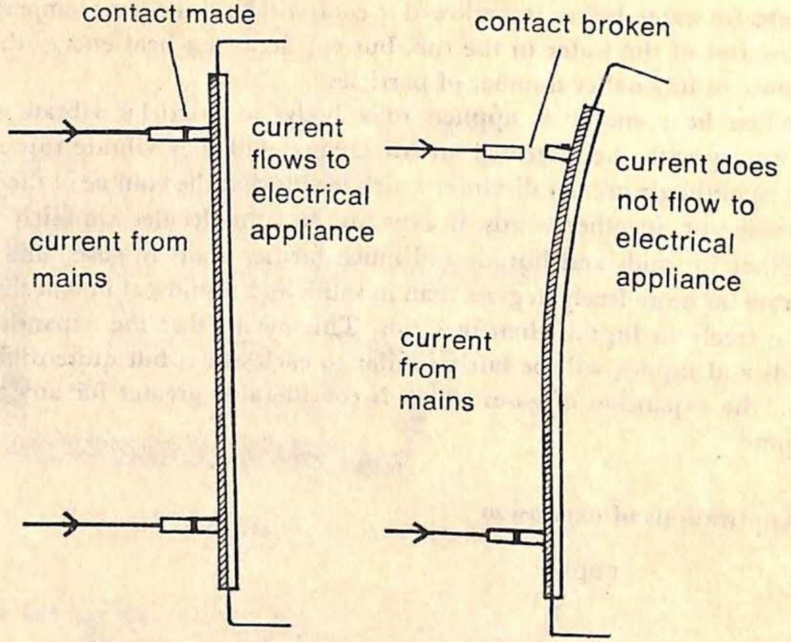

contact made
current flows to electrical appliance
current from mains
contact broken
current does not flow to electrical appliance
current from mains

Fig. 3.5 **Action of a bimetallic thermostat**

Fig. 3.5. As the temperature of the electric iron rises past a particular value, (which can be set on a dial according to the type of cloth being ironed), the bimetallic strip bends and curves away, breaking the contact and stopping the flow of current. When the iron cools back to the suitable temperature, the bimetallic strip straightens out, restoring the contact, and allows the current to flow again and provide heat. A bimetallic strip can also be used in automatic fire alarms. Fig. 3.6 shows how this is done. As the temperature rises, due to a fire, the bimetallic strip curves and makes contact with a contact screw thereby completing a circuit and causing an alarm bell to ring.

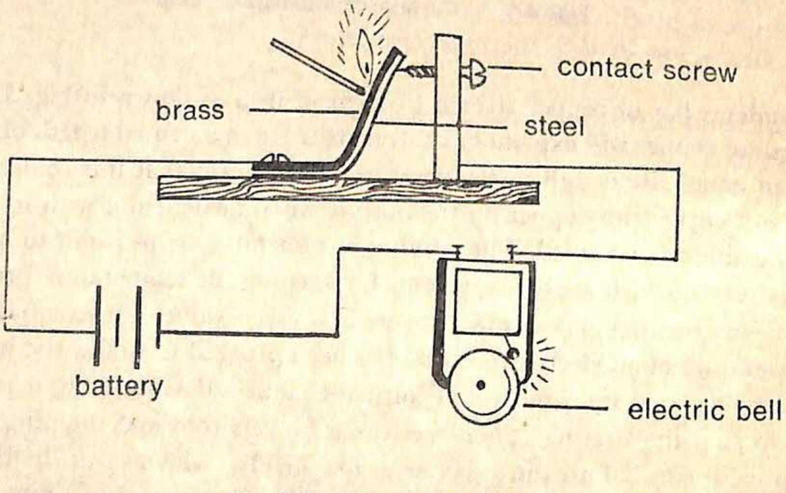


Fig. 3.6 **Automatic fire alarm**

A mixture of nickel and steel in the proportion 36% by weight of nickel to 64% of steel produces the alloy 'invar' which expands so very slightly on being heated that its expansion can be considered to be almost nothing. This means that a compound bar of invar and another metal will curve with invar on the inside when heated, and with invar on the outside when cooled.

Expansion and contraction enter frequently into our everyday lives. This can be appreciated more fully when it is realised what great forces are brought into play during expansion and contraction. Here is an example which is known as the 'bar breaker' (see Fig. 3.7). A metal rod is fixed at one end and has a hole running through it at the other end. When the rod is cold, this hole falls within a fixed metal piece through which the rod passes. When the rod is heated it expands and the hole emerges, and a stout metal pin is placed through it. On cooling, the rod contracts to its original position, and the stout metal pin snaps like a matchstick, as the hole retreats to its original position.

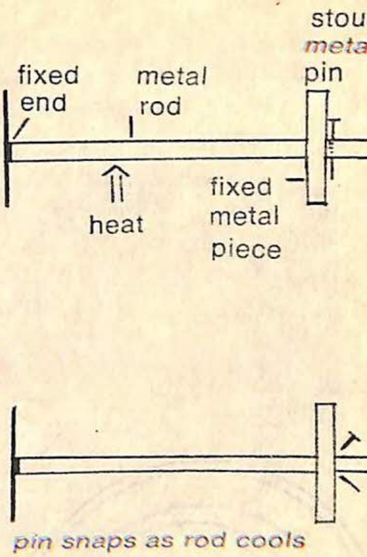


Fig. 3.7 **To show the great forc brought about by contraction**

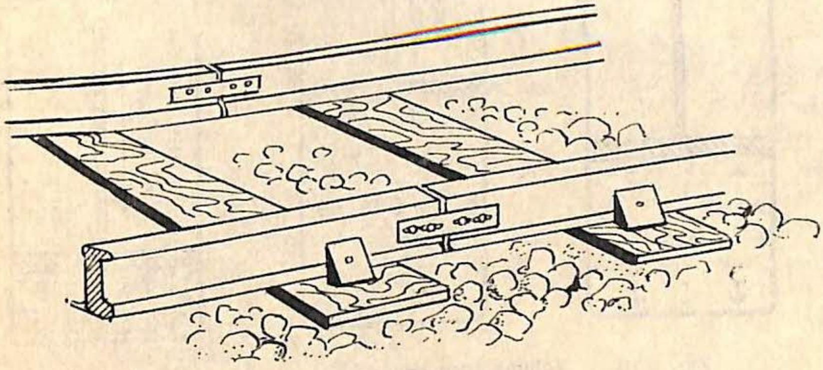


Fig. 3.8 **Gaps between railway tracks to allow for expansion**

Gaps must be left between sections of railway track or they would buckle as they expand with heat from the atmosphere. Fig. 3.8 shows how this is done. When electric wires are strung from pole to pole, they are strung with some sag, to allow for contraction during very cold weather or they would snap on contraction if fitted in a straight line from one pole to another. The metal roof of a shed must not be firmly fixed to the wall. Fig. 3.9 shows how it is arranged to allow for expansion during very hot weather. The fitting of the rim of a cart wheel is done by contraction. The rim is made of such a size as would fit tightly over the wheel. It is heated so that it expands and can be slipped over the wheel. On contraction it fits tightly and firmly over the wheel. Many more expansion and contraction effects will be discussed as we continue our study of Physics. In the meantime try and think of some more examples e.g. how to loosen the metal cover of a jar, the use of mercury in a thermometer, etc.

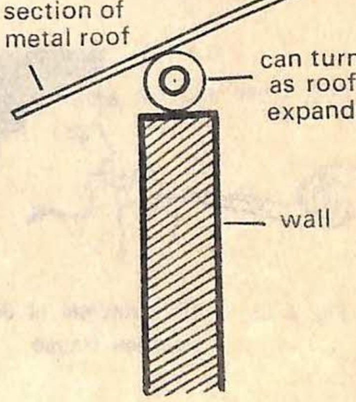


Fig. 3.9 **Metal roof of a shed — fixed so as to allow for expansion and contraction**

4. Gas Pressure

The expansion of a gas is more complicated than that of a solid or a liquid, because it does not depend only on temperature. The weight of any given volume of gas is considerably less than the weight of the same volume of solid or liquid. This means that in a gas the particles are spaced much farther apart, in which case a gas must be more compressible than a liquid or a solid. Also since the particles of a gas are moving in all directions with almost complete freedom, they will strike against the walls of any container which seeks to contain them. This impact of gas particles on the walls of its container is described as the *pressure* of that gas, and the container presses on the gas with an equal pressure to keep the gas contained. Thus the volume of a gas does not depend only upon its temperature, but also on its pressure, as Fig. 3.10 will show. Gas is contained in a vessel by means of a movable plunger. As the force exerted by the plunger on the gas is lessened by raising the plunger, the pressure of the gas is lessened and its volume is increased. As the force exerted by the plunger on the gas is increased by pushing the plunger down, the pressure on the gas is increased and its volume is decreased.

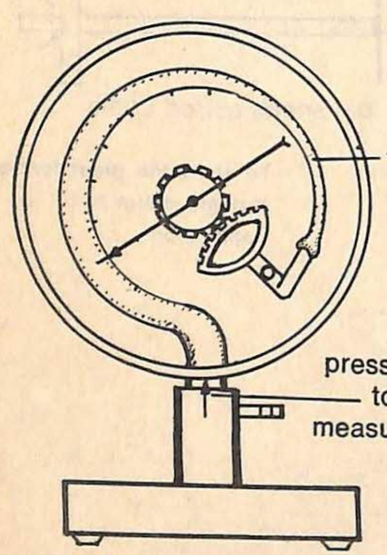


Fig. 3.11 **The Bourdon Gauge**

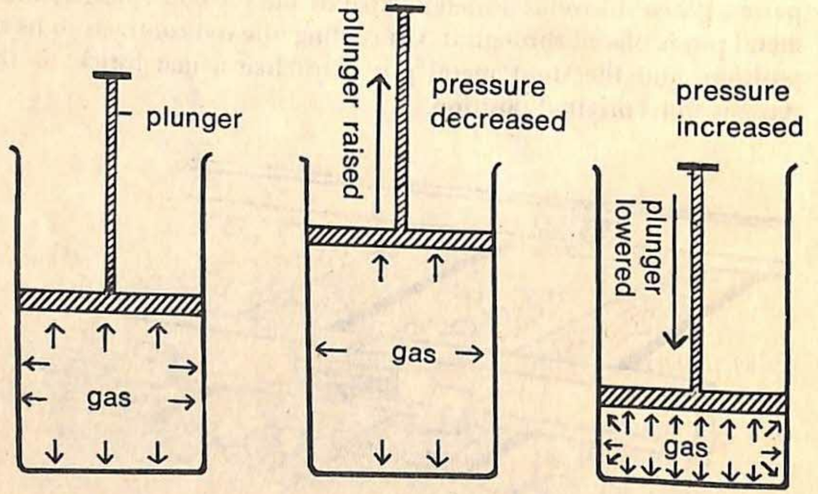


Fig. 3.10 **Volume of a gas depends on its pressure**

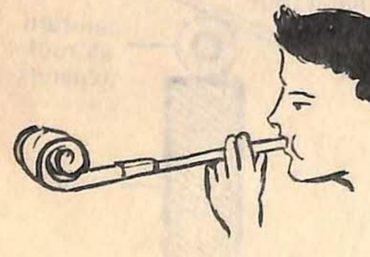


Fig. 3.12 **The principle of the Bourdon Gauge**

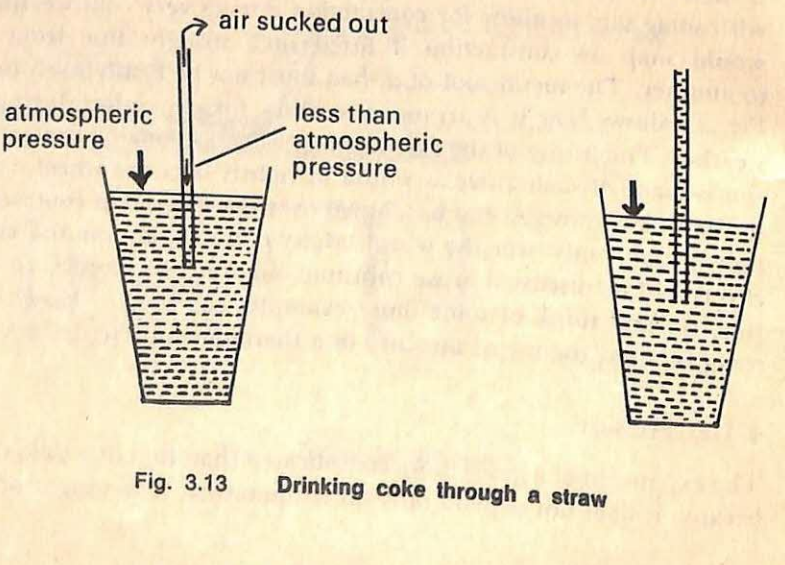


Fig. 3.13 **Drinking coke through a straw**

One way of measuring the pressure of a gas is by the *Bourdon gauge* shown in Fig. 3.11. It works on the simple principle shown in Fig. 3.12. The greater the pressure of the gas the stronger the tendency of the coiled tube to straighten out. Its tendency to straighten out can be indicated by the pointer on the scale.

The most common gas is air, and the pressure of this gas is of great importance to us. Consider the simple act of drinking through a straw as shown in Fig. 3.13. It is the pressure of the air or atmosphere which forces the drink up into the straw. If there was no atmospheric pressure we could not drink through a straw. Many other similar happenings, of greater importance in our lives, like pumping water up to overhead tanks, or giving an injection, would also be impossible if there was no atmospheric pressure. The pressure of the atmosphere is quite strong, as can be seen by the fact that it can crush a strong can as if it were a matchbox. This is shown in Fig. 3.14. When the can contained air the pressure of this air balanced the pressure of the air from outside. When the air was removed from inside the can, there was nothing to balance the pressure of the air from outside, and it crushed the can.

Fig. 3.15 shows two hemispheres which can fit together to form an air-tight sphere. As long as there is air inside the sphere to balance the pressure of the air outside, we can separate the hemispheres easily. But when the air is withdrawn from within the sphere, it takes a terrific force to pull against the air pressing on the outside of the sphere. This experiment was performed by Otto Von Guericke in a place called Magdeburg in Austria in the year 1651. Two teams of sixteen horses were needed to separate the hemispheres which were 1 foot in diameter. Such hemispheres are now referred to as 'Magdeburg hemispheres'.

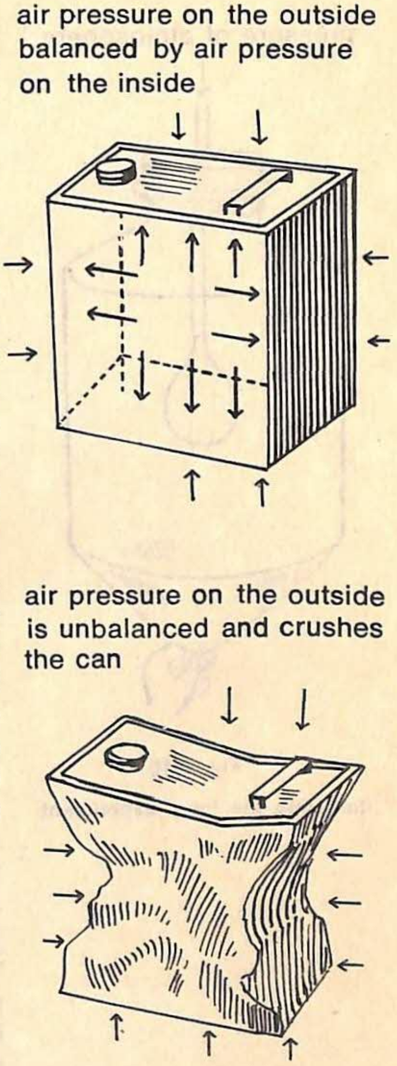
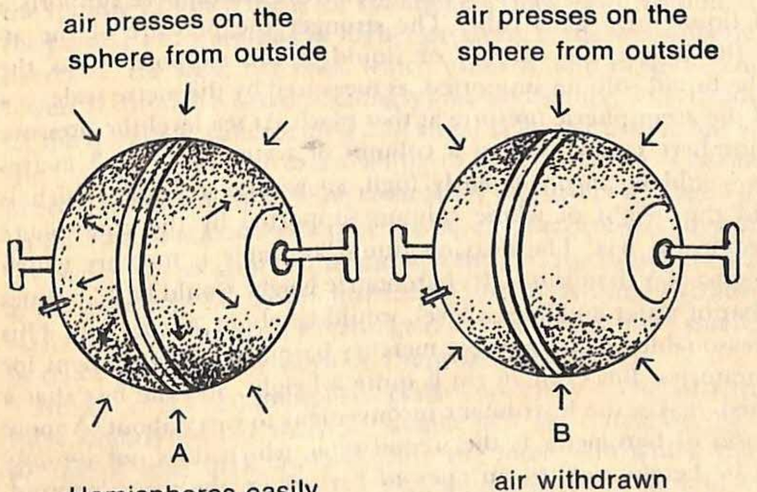

air pressure on the outside balanced by air pressure on the inside
air pressure on the outside is unbalanced and crushes the can

Fig. 3.14 **'Crushing the Can' experiment**


air presses on the sphere from outside
air presses on the sphere from outside

A

Hemispheres easily separated

B

air withdrawn
Hemispheres very difficult to separate

Fig. 3.15 **The Magdeburg Hemispheres**

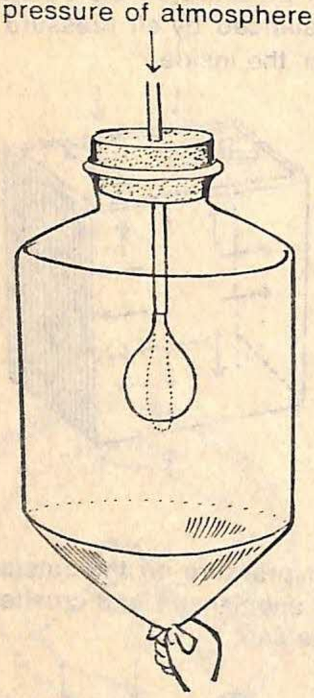


Fig. 3.16

'Imitating the lung' experiment

Fig. 3.16 is another example of air pressure. A deflated balloon is attached to a tube passing through the stopper of a glass bell jar. As the rubber sheet closing the lower end is drawn outwards, this increases the volume of the air inside the bell jar and outside the balloon. This lowers the pressure on the outside of the balloon, and the pressure of the air inside the balloon pushes the rubber of the balloon outwards, thus inflating it. As soon as the rubber sheet is released and returns to its original position, the balloon is again deflated, because the pressure on the outside of the balloon is again raised to its previous strength. This same pressure that crushed the can, and kept the hemispheres together, acts on our bodies all the time but we do not feel this because there are fluids within the body which provide a counter-balancing pressure, and we are adjusted to this balance. It is only when the pressure of the atmosphere on us is drastically changed and this balance is upset that we feel discomfort. Thus when a person goes down from the high mountains to sea level, there is a discomfort felt until that person adjusts to the greater pressure at sea level. Aircraft which fly at great heights must have their passenger cabins 'pressurised', i.e. the pressure inside the cabins must be increased sufficiently, or the passengers would feel great discomfort, in fact serious illness, at the greatly reduced atmospheric pressure of the high altitudes.

Another important effect of atmospheric pressure is its influence on weather. Air moves from high pressure to low pressure, so if the atmospheric pressure at any place falls, winds will blow in to that place carrying rain with them. If the atmospheric pressure falls appreciably, it means bad weather ahead.

All this shows that a knowledge of the atmospheric pressure is important. The instrument used for measuring atmospheric pressure is the *barometer.* There are two types of barometer. The first is the liquid barometer, shown in Fig. 1.9. Here the pressure of the atmosphere supports a column of liquid in a glass tube. The stronger the pressure of the atmosphere, the longer the column of liquid it can support. Thus the height of the liquid column supported, as measured by the metre scale, is a measure of the atmospheric pressure at that place. At sea level the pressure of the atmosphere could support a column of water about 10.3 metres high. This would be inconveniently high, so we use a liquid which is heavier and the height of whose column supported by the atmosphere would therefore be less. The heaviest liquid available is mercury which is 13.6 times heavier than water. Its barometric height would be 13.6 times less than that of water and, at sea level, would be about 76 cm high. This is a more reasonable height, and the mercury barometer is convenient for use in laboratories. But even 76 cm is quite a height, and the fact that a liquid is used, makes the instrument inconvenient to carry about. A more portable form of barometer is the second type, which does not use any liquid and is therefore called an *aneroid barometer,* the word 'aneroid' meaning 'without liquid'. The working of an aneroid barometer is shown in Fig. 3.17.

A is a partially evacuated box with a wavy undulating surface. It is partially evacuated to make it more responsive to variations of atmospheric pressure, and its undulating surface presents a greater area than a flat sur-

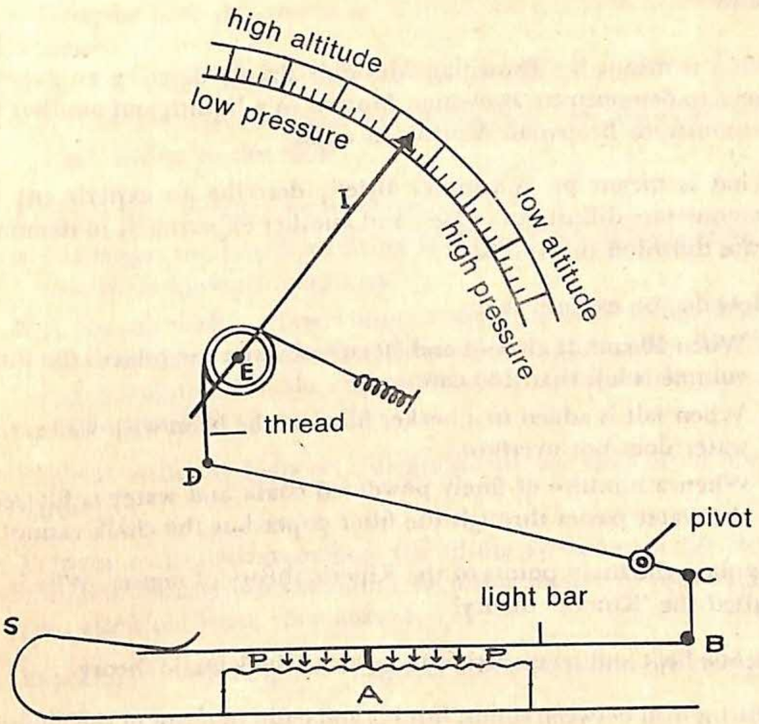


Fig. 3.17 **Working of an aneroid barometer**

face would, and so experiences a greater total force. As the atmospheric pressure P increases, the top of the box is moved down, lowering the light bar attached to it. This lowers B, which also lowers C, and this causes D to rise through a considerably greater distance. This winds the thread on to the spindle E, which turns the spindle in a clockwise direction, thus moving the pointer I to a reading of higher pressure. If the atmospheric pressure P decreases, the light bar rises, which raises B, and raises C, and therefore lowers D through a correspondingly greater distance. This winds the thread off the spindle E, thus turning it in an anti-clockwise direction which moves the pointer to the left to a reading of lower pressure. The spring S is to prevent the box A from being completely crushed or damaged by too heavy an increase in atmospheric pressure. As the atmospheric pressure decreases the higher up we go into the atmosphere, this instrument can also be used as an *altimeter* i.e. as an instrument for measuring altitude, or height above sea level. Its main advantage is its portability. Very small models can be made which can be worn on the wrist like a watch.

At sea level the atmosphere presses on every 1 cm^2 of surface with a force slightly greater than the weight of 1 kg. Calculate the area of the surface of your desk, and calculate the force with which the air presses down on your desk. Can you make an estimate of the total force the air exerts on your entire body area?

Questions

1 What is meant by 'Brownian Motion'? Briefly describe an experiment to demonstrate Brownian Motion in a liquid, and another to demonstrate Brownian Motion in a gas.

2 What is meant by 'diffusion'? Briefly describe an experiment to demonstrate diffusion in gases, and another experiment to demonstrate diffusion in liquids.

3 How do you explain that:

a When 50 cm^3 of alcohol and 50 cm^3 of water are mixed, the final volume is less than 100 cm^3.

b When salt is added to a beaker filled to the brim with water, the water does not overflow.

c When a mixture of finely powdered chalk and water is filtered, the water passes through the filter paper but the chalk cannot.

4 Explain the main points of the Kinetic theory of matter. Why is it called the 'Kinetic' theory?

5 Define heat and temperature in terms of the Kinetic theory.

6 Distinguish between solids, liquids and gases in terms of the Kinetic theory.

7 Draw a diagram to show how a bimetallic strip can be used to automatically stop and start the current to an electrical appliance.

8 Mention two examples of expansion and contraction in daily life. Explain, with the help of diagrams, the effect of the expansion or the contraction, and explain whether it would be a help or a hindrance.

9 Draw a diagram to show how a bimetallic strip can be used to start an automatic fire alarm. Briefly explain how the fire alarm works.

10 a Describe an experiment to show that copper expands more than iron when both are heated the same.

b Explain why a dent can often be removed from a ping-pong ball by holding it in front of a fire.

11 What are pressurized cabins on passenger aeroplanes? Why are they necessary?

12 Why can a barometer, which measures air pressure, be used to measure the height of a mountain?

13 a Explain why you can draw lemonade through a straw by suction.

b The straw sometimes collapses when an orange pip or lemon seed gets stuck in the open end of it. Explain why.

c Is there any limit to the length of the straw which could be used?

14 a Describe how you would set up and use a simple mercury barometer.

b Why is water not suitable for use in a barometer?

c Would a barometer read lower inside a building than in the open, owing to the roof?

15 Explain why, giving reasons in each case:

a Passengers in aeroplanes flying at considerable heights often find that their fountain pens leak.

b A tin can with a screw stopper contains a little water. The can is heated, the water boils and steam issues plentifully. The heating is stopped, and the can quickly stoppered. As the can cools it gets crushed.

16 Explain, with the help of a diagram, the working of an aneroid barometer.

17 Explain with a diagram how the filling system of a pen works. Unscrew the cover and examine the filling section of your fountain pen, and then write your answer.

18 Explain, with the help of a diagram, how a Bourdon pressure gauge works.

4

Detecting the Environment

WE have said in Chapter 1 that in Physics we study the working of our Universe, and that everything in our Universe is either matter or energy. In Chapter 2 we studied energy and in Chapter 3 we studied matter.

All the matter and energy that is immediately around us is called our environment. How do we detect this environment? The answer is with our *five senses: sight, hearing, touch, taste* and *smell*. We said in Chapter 1 that our senses cannot always be relied on to give accurate information, and that we need instruments to do this. But the fact remains that we do detect our environment all the while with our senses, and, for normal purposes, these senses give us sufficiently accurate information. You are reading this page with your eyes. In class you *listen* to the teacher, and *see* what he or she writes on the board and does by way of experiment or demonstration. Our sight and our hearing are very precious gifts; without these senses we would be cut off to a very great extent from our environment, and we would miss most of the beauty and wonder of life. We should therefore, at the very outset, study how these work so that by understanding their working we can learn to appreciate our senses and to protect and develop them as much as we can. This chapter will be divided into two parts: the first dealing with the eye and light, and the second with the ear and sound. We shall end the chapter with a brief mention of the other means of detecting the environment viz. touch, taste and smell.

1. The eye and light

(i) *The structure of the eye*

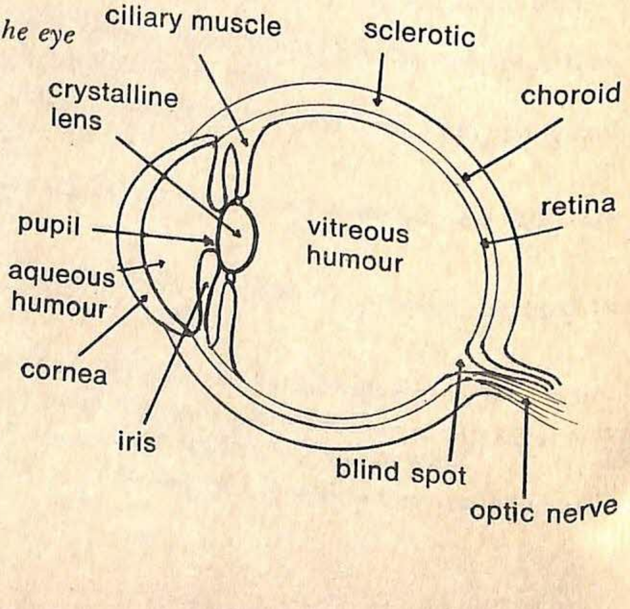


Fig. 4.1 **The structure of the eye**

The eyeball is approximately spherical in shape and about 2.5 cm in diameter. The wall of this sphere is composed of two major layers, an outer layer and an inner layer. The outer layer, called the *sclerotic*, is a tough, opaque, white substance forming the white of the eye. The front portion of this sclerotic coat forms a transparent curved section called the *cornea* that protects the eye. The inner layer, the *choroid coat*, is black to prevent internal reflection and to protect the light-sensitive parts of the eye. The *vitreous humour* and *aqueous humour* are jelly-like materials filling the spaces within the eyeball and helping to keep it spherical in shape. Behind the cornea is a coloured diaphragm called the *iris*. This is really an extension of the choroid coat and its colour varies with different human beings. In the centre of the iris is a circular opening called the *pupil*, which appears black owing to the black interior of the eye. The iris contains muscles that dilate and contract the pupil, adjusting the eye to different amounts of light. The pupil is dilated in dim light and contracted in bright light. This action occurs involuntarily i.e. without any control on our part. Behind the pupil and the iris is the *crystalline lens*. This is a transparent body whose curvature in front is considerably less than the curvature of its back surface. This lens is held in place by suspensory ligaments which are attached to the choroid coat. In the choroid layer, near the suspensory ligaments, are small *ciliary muscles*. These muscles are very important because their action can adjust the thickness of the eye lens to just the correct curvature for seeing an object at a particular distance. The closer the object looked at, the thicker and more curved the eye lens has to be to see it clearly. The eye lens is at its thinnest when looking at very distant objects. This power of the ciliary muscles to adjust the curvature of the eye lens is called the *power of accommodation* of the eye. The eye sees an object by the light from that object that passes through the eye lens and forms an image of it on the *retina*, which is the innermost layer of the eye and is sensitive to light. The sensation of the image formed on the retina is carried to the brain by the *optic nerve*. As this sensation is received by the brain, we 'see' the object.

(ii) *The action of a camera*

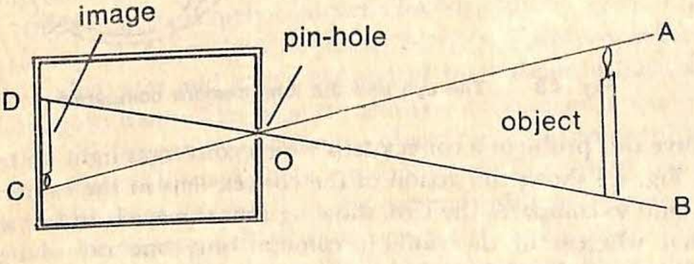


Fig. 4.2 **Action of a pinhole Camera**

The simplest of all cameras is the pinhole camera which is an interesting application of the fact that light travels in straight lines. Its principle of action is shown in Fig. 4.2. It consists of an opaque box with a pinhole in the middle at one end, and a translucent screen (a piece of ground glass or oiled paper) at the other end. If a lighted candle is placed a little distance in front of the pinhole, an inverted image of the candle will be seen on the translucent screen. If we replace the translucent screen with photographic film or a photographic plate, a photograph of the candle can be obtained.

The disadvantage of this very simple form of camera is the very long exposure needed, because of the small amount of light admitted through the pinhole. The photograph is recorded on the photographic film or plate by the chemical action of light on the chemicals with which the film or plate is coated. If very little light strikes the film, as in this case, it will take longer for the chemical action to be completed and for the image to be recorded on the film or plate. Since the object being photographed must not move throughout the time this action of light on the film is going on, this means that we can only use the pinhole camera to take photographs of stationary objects like a building, scenery etc.

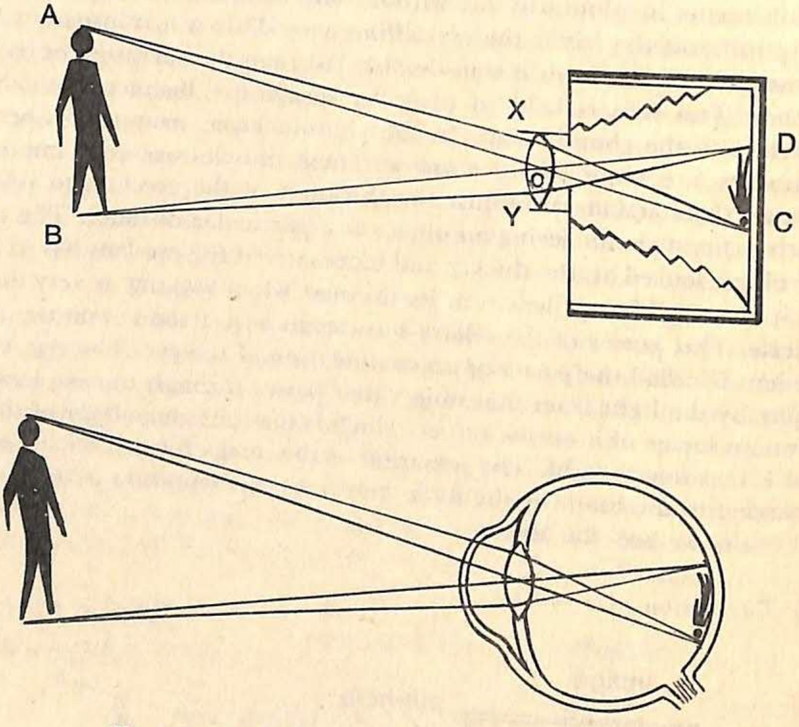


Fig. 4.3 **The eye and the lens camera compared**

To solve this problem a convex lens which converges light on to a point is used. Fig. 4.3 shows the action of the convex lens in the camera and in the eye, and so compares the two, showing that the eye is in fact a camera. Note that whereas in the pinhole camera, only one ray of light, AO, from the point A formed the image point C, in the case of the convex lens camera a whole bundle of rays, of which AX and AO are the outermost, form the image point C. Similarly the whole bundle of rays between BY and BO form the image point D. Since much more light is falling on the photographic film in this case, the chemical action which records the image is completed faster, so very short time exposures of a fraction of a second are enough. This means that the range of subjects that can be photographed is considerably increased.

(iii) *The Eye and the Camera compared*

1. Both have a convex lens which forms an upside-down, or inverted, image of the object.
2. Both are blackened inside to prevent internal reflection. Any rays that are not to be received on the retina or camera film are absorbed by the black choroid coat, or black inside surface of the camera.
3. Both can adjust the amount of light that enters the lens. In the eye the pupil dilates in dim light to allow more light in, and contracts in bright light to lessen the amount of light that enters. In the camera there is a shutter which can be adjusted to regulate the size of the opening through which light enters the lens. In dim light this opening is left quite large, and in bright light it is made much smaller.
4. In the camera the image is recorded by the chemical action of light on the chemical (silver bromide) with which the photographic film is coated. In the eye the image is recorded in the brain by the sensations caused by the light which falls on the retina and forms the image there, being carried to the brain by the optic nerve.
5. In the camera, in order that the image of objects at different distances is always formed on the film and not in front of it or behind it, the lens must be moved back or forth to the appropriate position. In the eye, in order that the image of objects at different distances is always formed on the retina and not in front of it or behind it, the eye lens is thickened or thinned to the appropriate curvature by the action of the ciliary muscles.

Note that whereas 1, 2 and 3 are points of resemblance or similarity, 4 and 5 are points of difference.

(iv) *Vision*

We shall now explain in greater detail the mechanism of vision, or, to put it simply, how we see things.

The retina is an extremely complex film covering the greater part of the inside surface of the eyeball. It contains about 7 million separate nerve endings, called *rods* and *cones* because of their shape, which respond to light falling on them. The rods are sensitive to changes in the strength of light while the cones are sensitive to colour. Near the centre of the retina, where the image is formed, there are only cones. The rest of the retina has a mixture of rods and cones with the cones steadily decreasing in number away from the centre until there are only rods at the outer edges of the retina. There are about one million separate nerve fibres that connect these nerve endings, the rods and cones, to the brain. These one million or so separate nerve fibres make up what we earlier called the optic nerve. The optic nerve branches before it meets the brain so that the nerve fibres from the left half of each eye connect to one side of the brain, while those from the right half connect to the other side of the brain.

When an inverted image of an object falls on the retina, each rod and cone sends a series of nerve impulses to the brain. Several million of these impulses are carried by the optic nerve to the brain every second and are somehow translated by the brain into vision of the object right way up. So vision is a mental action and does not take place in the eyes. For this reason brain injuries may affect the vision even though the eyes are perfect.

How does the eye detect colour? The most significant fact is that the sensation of white can be produced not only by all the colours of the spectrum together, but also by three single colours, red, green and blue. Further, it can be demonstrated that any colour sensation can be produced by blending these three colours in suitable proportions. Scientists still do not know exactly how our eyes react to colours. The most generally accepted theory is that the nerve-endings sensitive to colour, the cones, are of three types – one type sensitive to red, one to green, one to blue. If all three types are equally stimulated we see the colour known as white. Lack of stimulation of any of the three types, or *receptors* as they are called, gives the sensation of darkness or blackness. When red coloured light enters the eye, it stimulates only the red receptors and the sensation of seeing the colour red is produced in the brain. If only those receptors that are sensitive to green are stimulated we see the colour green. When yellow light, however, enters the eye the red and green receptors are equally stimulated because yellow is a mixture of equal proportions of red and green. We see the colour known as magenta if the receptors to red and blue are equally stimulated and the green not at all, because magenta is a combination of equal parts of red and blue. This is a very simplified explanation of colour vision, and recent experiments in colour vision carried out by experts show that there are many more complications that cannot be gone into at this stage.

An important feature of colour vision is *colour blindness,* which is a defect of the eye which causes some persons to confuse two or more colours which others can readily distinguish. It is believed that about 6 to 7 per cent of men and less than 1 per cent of women are colour-blind. Most colour-blind persons cannot distinguish between reds, greens and yellows, or between blue-greens, blues, and violets. The first group of colours appear to them as shades of yellow, and the second group of colours seem to be shades of blue. This type of colour blindness is thought to be due to a defect in one of the three types of receptors. Other, less common, forms of colour blindness seem to be caused by defects in two or even all three types of colour receptors. Colour vision test cards have been prepared which can test the degree of colour blindness of any person. In another type of test, the subject has to look at successive pages of a book on which numbers printed in dots of various shades of one colour are on a background of dots of another colour. The numbers are visible to someone with normal vision but a colour-blind person cannot see them.

The area occupied by the optic nerve is insensitive to light. This part of the retina is known as the *blind spot,* because if the image is formed here the object will not be seen by the eye, because its image will not be registered in the brain. Since the optic nerve leaves each eye on the side nearer to the nose, the images in both eyes never fall simultaneously on the blind spots. The existence of the blind spot can be demonstrated as follows. Close one eye, the left eye for instance, and look at the cross in Fig. 4.4 with the right eye. Although you are not looking directly at it, the black circle is also visible. Now move the book towards the eye, and at a certain position of the book the black circle seems to disappear. Its image has fallen on the blind spot of your right eye. You can find the blind spot of your left eye by closing the right one and staring at the black circle with your left eye. Move the book towards you and at a certain position the cross seems to disappear. Its image has fallen on the blind spot of your left eye.

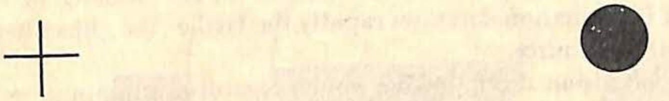


Fig. 4.4 **To show the existence of the blind spot**

Human beings have highly developed *binocular* (two-eyed) *vision.* Your two eyes receive nearly, but not quite, the same impression, for each eye views the same object at the same time from a slightly different point. This enables you to do two things at one time. You can judge the distance of an object and you can estimate its depth and size. Your brain learns by experience to blend the two images into one.

The following experiment (see Fig. 4.5) demonstrates how we can estimate distances more easily with two eyes than we can with one. Have a friend hold a thin piece of wire away from other objects. With another similar wire in your hand, try to touch the end of his wire when it is about as far away as you can reach. You will find that you can do this with considerable accuracy. Now try and do the same thing with one eye closed. You will find it much more difficult to bring the two wires together.

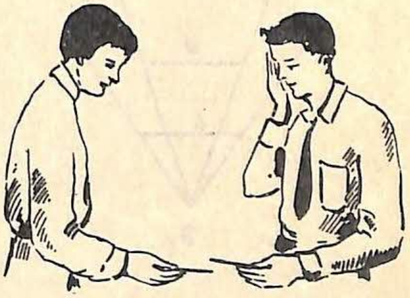


Fig. 4.5 **To demonstrate the need for two-eye vision**

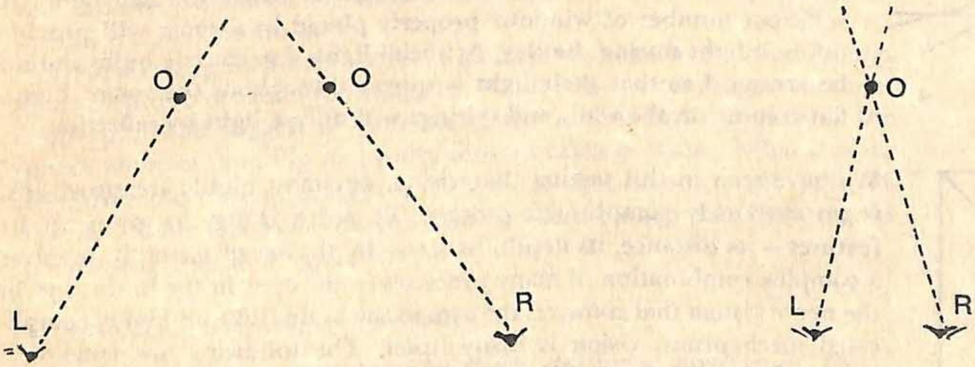


Fig. 4.6 **How two-eye vision helps us**

How two-eye vision enables us to fix the position of an object is simply explained by Fig. 4.6. The left eye tells us that the object is somewhere on the line LO, but does not tell us exactly where along LO. The right eye tells us that the object is along RO, but does not tell us exactly where along RO. The two eyes together tell us that the object is both on LO and on RO, and therefore that it has to be where these two lines cross each other i.e. at the position O.

We should also note that the size and position of nearby objects also helps us to estimate the distance, size and shape of any object we are looking at.

Another very important factor connected with vision is *illumination*. Good vision depends not only on the proper functioning of the eye, but on good illumination as well. It is important to remember that illumination depends both on the illuminating power of the source of light e.g. its candle power if it is an electric bulb, and on the distance of the source, and that illumination decreases rapidly the farther the object being looked at is from the source.

For good vision the following points regarding illumination should be observed.

1. The illumination must be sufficient. If it is too weak the eyes will be strained.

2. The contrast between the illumination of the work being studied and that of the surroundings should not be great. If the work is brightly lit and the rest of the room dark, the pupil of the eye must be adjusted each time you look away from your work and then back to it. Since the dilation and contraction of the pupil is worked by muscles in the eyes, your eyes become tired sooner than they would if the illumination were more uniform.

3. If a light is improperly placed when you are reading, there may be a bright spot, called 'glare', on the paper. It is very difficult to see clearly inside the area covered by glare. This glare can be avoided by illuminating your work from the side or from behind.

4. The best illumination for good vision is obtained from a source which spreads the light evenly. Such light is called 'diffused light'. A sufficient number of windows properly placed in a room will provide diffused light during the day. Artificial lights e.g. electric bulbs should be arranged so that their light is spread throughout the room. Light, flat colours on the walls and ceilings will diffuse light by reflection.

We have seen in this section that vision, our most highly treasured gift, is an extremely complicated process. To see a thing, to grasp all its features – its distance, its depth, its size – by the act of seeing it, involves a complex combination of many processes in the eyes, in the brain, and in the nerve system that connects the eyes to the brain. Like all highly complicated mechanisms, vision is easily upset. The following are some well known optical illusions. Those in Fig. 4.7 concern illusions in shape and size. Fig. 4.8 describes an illusion in colour.

Fig. 4.7. Nos. 1, 2, 3. Look at lines 'a' and 'b' and visually compare their lengths. Now measure them.

No. 4. Look at the horizontal lines 'a' and 'b' Are they parallel? Check by measurement.

No. 5. The inside square appears to shift back and forth.

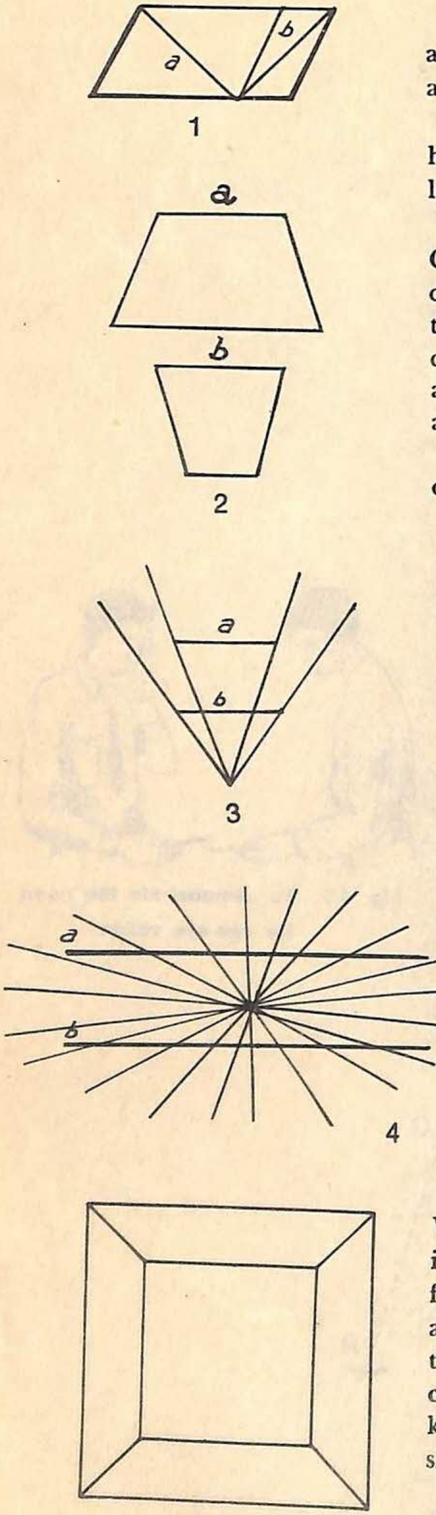


Fig. 4.7 **Optical illusions in shape and size**

Fig. 4.8. Copy out this figure. Shade the ring a uniform grey with pencil. Colour the rectangular area, except for that part of it which is part of the ring, black with black ink or paint. Does the ring look uniformly grey?

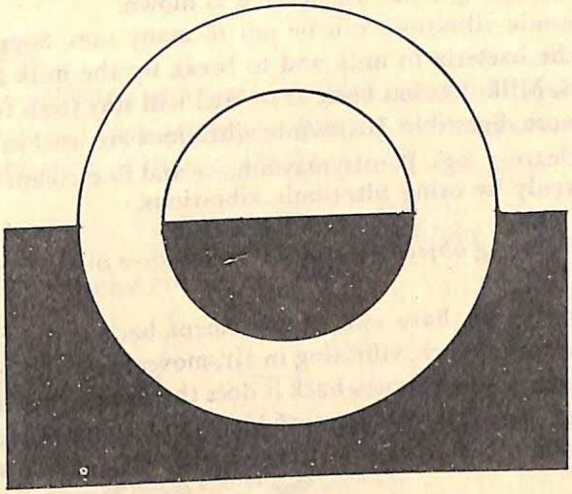


Fig. 4.8 **Optical illusion in colour**

2. The Ear and Sound

(i) *All sound is caused by vibration of the sounding body.*

If you place your finger on your throat while you talk, you can feel something moving. If you place your finger next to a guitar string while the instrument is being played, you can feel the strings move back and forth very rapidly. This back and forth motion, in the throat and in the guitar strings, is called *vibration.*

Strike a tuning fork with a rubber hammer and touch one of its prongs against a pith ball as shown in Fig. 4.9. What does the resulting movement of the pith ball suggest to you? Strike the tuning fork again with the rubber hammer, and dip its prongs into a beaker of water. What do you see? Strike the tuning fork again with the rubber hammer, and press its stem on a table top. What do you hear? Is the table top also vibrating? If so, how was it set into vibration?

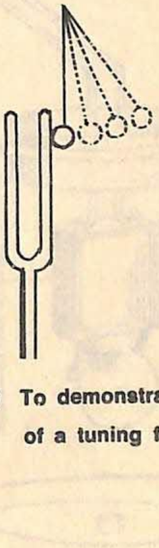


Fig. 4.9 **To demonstrate the vibration of a tuning fork**

(ii) *All vibration does not cause sound.*

The number of complete vibrations (back and forth movements) that a vibrating body makes in one second is called the *frequency* of its vibration. If an object vibrates at any frequency between 20 and 20 000 vibrations per second, its vibrations will affect the average human ear so that sound is heard. A person cannot wave his arms fast enough to produce sound, although bees can move their wings so rapidly that a buzzing sound is heard when they are flying.

When vibrations occur too rapidly for the human ear to hear, they are called *ultrasonic vibrations* ('ultra' means 'beyond' and 'sonic' refers to sound). There is a type of whistle, known as a silent dog whistle, which produces vibrations of a frequency more than 20 000 vibrations per second which a human being cannot hear, but a dog, who can hear sounds caused by frequencies up to 40 000 vibrations per second, can hear the whistle and can be trained to come whenever it is blown.

Ultrasonic vibrations can be put to many uses. Some dairies use them to kill the bacteria in milk and to break up the milk fat into very small particles. Milk that has been so treated will stay fresh for a longer period, and is more digestible. Ultrasonic vibrations are used in controlling smoke and in clearing fogs. Paints, mayonnaise and face cream can each be mixed more evenly by using ultrasonic vibrations.

(iii) *A vibrating object produces a disturbance in the material surrounding it.*

Vibration, as we have said, is movement back and forth. When a body, such as a tuning fork, vibrating in air, moves forward, it compresses the air near it, and when it moves back it does the reverse. Thus areas of alternate high and low pressures are produced in the air surrounding it, which follow each other in rapid succession as the body keeps vibrating back and forth (see Fig. 4.10). This sets up a mechanical disturbance in the air, and if the vibrations are within the limits of audibility i.e. between 20 to 20 000 vibrations per second, this disturbance is called a *sound wave*. Here we have described its production in air, but sound waves can also travel along other materials like water or iron. There must be some material substance to transmit the disturbance. *Sound cannot travel through a vacuum*. This can be demonstrated by the apparatus shown in Fig. 4.11, in which an electric bell is operated within a jar containing air. The sound of the bell is heard. If the air is removed from the jar, the sound of the bell gets weaker and weaker, until finally it can scarcely be heard, although the bell can be seen to be operating as vigorously as ever. If all the air could be removed from the jar, there would be no sound from the bell. If air is readmitted into the jar, the sound will be heard again.

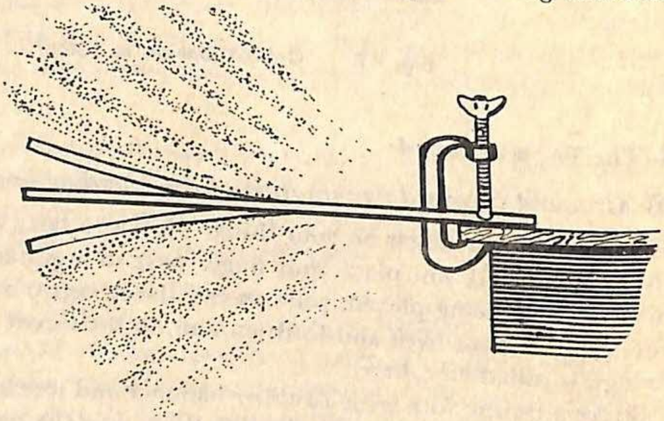


Fig. 4.10 **Alternate compressions and rarefactions caused by a vibrating body**

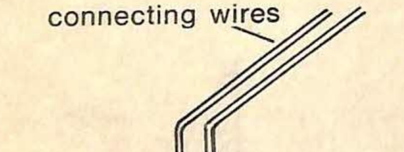


Fig. 4.11 **Sound cannot travel through a vacuum**

There can be no sound in a vacuum because there is nothing around the vibrating object through which the mechanical disturbance (the alternate areas of high and low pressure described above) can travel to reach a person's ear. This is one very important difference between light and sound; light can travel through a vacuum, sound cannot.

(iv) *The Human Ear*

The human ear is a delicate organ, parts of which control the body's sense of balance and parts of which are responsible for receiving sound waves and transmitting the effect of these to the brain.

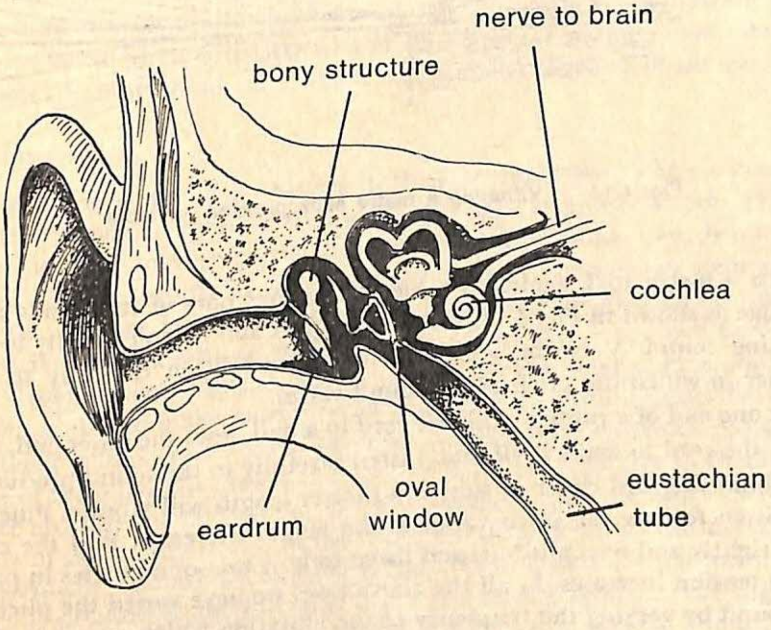


Fig. 4.12 **The Human Ear**

Sound waves, collected by the outer ear, make the *ear drum* vibrate. This movement of the ear drum is conveyed through the middle ear by three bones, called the hammer, anvil and stirrup, to the *oval window* which is at the innermost side of the middle ear. Beyond the oval window is the inner ear. The part of the inner ear which is concerned with hearing is called the *cochlea*. It is a spiral cavity, shaped something like a small snail shell, and filled with a fluid. A membrane called the basilar membrane, containing about 30 000 nerve endings, passes along this spiral cavity. Vibrations of the oval window produce pressure changes on the fluid in the cochlea, and these pressure changes are picked up by the nerve endings in the basilar membrane which sends nerve impulses along the *auditory nerve* to the brain which interprets these impulses as the hearing of the sound. The ear does not hear – it merely receives sound waves which are transmitted as impulses to the brain. It is the brain which translates these impulses into sound.

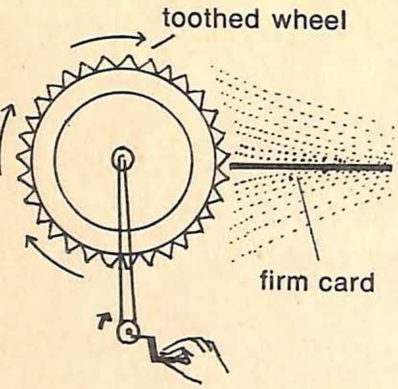


Fig. 4.13 **Toothed wheel vibrating a card**

(v) *The pitch of the sound depends on the frequency of its vibration.*

Fig. 4.13 shows a toothed wheel vibrating a card. As each tooth of the wheel hits the card it makes it vibrate, so the faster the wheel rotates, the faster the card will vibrate. The wheel is made to rotate faster and faster, and as the card vibrates faster and faster the pitch of the sound it gives out rises higher and higher.

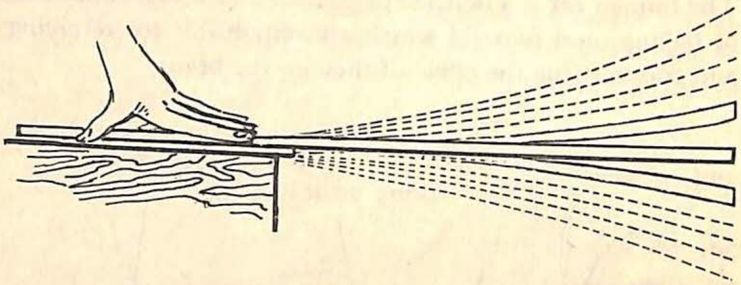


Fig. 4.14 **Vibrating a metre stick pressed on table**

Press a metre stick against a table top so that part of it extends over the edge as shown in Fig. 4.14. Vibrate this part and listen carefully to the resulting sound. Vary the vibrating length and listen carefully to the manner in which the pitch of the sound varies.

Fix one end of a rubber or elastic cord to a nail, hold the other end, and pluck the cord to make it vibrate. Listen carefully to the sound produced. Now hold the cord closer in so that a shorter length will vibrate. Pluck it and listen to how the pitch varies as the length decreases. Pull the cord more tightly and now pluck it, and listen to how the sound varies in pitch as the tension increases. In all the above cases we have varied the pitch of the sound by varying the frequency of the vibration which caused it. The more the frequency of vibration, the higher the pitch of the sound produced. The less the frequency of vibration, the lower the pitch of the sound produced.

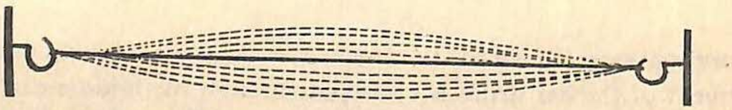


Fig. 4.15 **Rubber or elastic cord fixed to nails and plucked to vibrate**

(vi) *How we hear sounds of different pitch.*

It is thought that the judgement of pitch by the ear is due to the structure of the basilar membrane. The 30 000 or so nerve endings it contains respond to different frequencies. Low frequency sounds stimulate some of these nerve endings, high frequency sounds stimulate others. For different frequencies, the impulses sent to the brain are different, and the brain registers these as sounds of different pitch.

It will be realised from this that pitch in sound corresponds to colour in light. The ear however is much more sensitive in this respect, and can detect differences in pitch more sensitively than the eye can detect differences in colour.

(vii) *Care of the ears.*

The ears are important organs and should receive proper care. One should never remove wax from the ear with a pointed object as this might damage the ear drum. It is dangerous to shout loudly in someone's ear, or to hit someone on the ears, for the sudden pressure change caused by a loud noise or a sharp blow may injure the ear drum. You should also avoid blowing your nose too hard when you have a cold since the ear may become infected through the eustachian tube which connects the throat and the ear.

Conclusion

Living things respond to changes in their environment. Their success or failure depends on whether they make the right responses or not. Thus a flowering plant survives largely because its roots grow downwards into the soil to obtain a supply of water and minerals and because its stem grows upwards, so that leaves can obtain light and carbon dioxide for photosynthesis. In a similar way an animal's responses take it towards food and away from danger. Human beings possess special sense organs, and are therefore able to make more precise responses than other, lesser developed, living beings. The human body has an elaborate system of receptors. Some of these like the organs of taste and smell are receptive to chemicals. There are also several types of touch receptors. This wide range of receptors is of great importance in our lives, for with them we can detect the environment, and can avoid what is harmful in it and move towards that which is pleasant or helpful in it. Some receptors respond to the slightest stimulus, while others are only stimulated by more intense stimuli, but *when any receptors are stimulated sufficiently, signals pass along nerves leading from them to the central nervous system in the brain.* Within this system the mass of information received from receptors can be acted upon immediately, or the reaction or response to the information is stored in the brain for future reference i.e. it is memorised. This is a highly simplified description of how we detect, and react to, our environment, that part of the Universe which is immediately around us. The detailed study of the senses is highly complicated, and falls into the area of biological science called physiology.

Questions

1 Explain the part played by each of the following in the protection and working of the eye:

(*a*) cornea, (*b*) choroid coat, (*c*) pupil, (*d*) eye lens, (*e*) retina, (*f*) optic nerve.

2 What are 'rods' and 'cones'? What part do they play in vision by the human eye?

3 Why is a very long time exposure necessary for taking photographs with a pinhole camera? How does the convex lens in a lens camera lessen the time exposure required for taking a photograph?

4 Explain three similarities between the human eye and a lens camera.

5 Explain two differences between the human eye and a lens camera.

6 Briefly explain the generally accepted theory of colour vision.

7 What is meant by the 'blind spot' of an eye? How would you demonstrate its existence for each eye?

8 In what ways is binocular vision more accurate and helpful than single eye vision?

9 What four principles should be observed so that the best possible illumination is obtained for reading purposes.

10 Which of the following statements is correct?

a All vibrating objects produce sound.
b All sound is produced by vibrating objects.

Explain your answer fully, and with at least one example.

11 What are ultrasonic vibrations? State two uses to which they can be put.

12 What is necessary for the transmission of a sound? Describe an experiment to show that sound cannot travel through a vacuum. Can light travel through a vacuum?

13 Briefly describe what happens inside the ear from the time a sound wave enters the outer ear till the time the sound is heard in the brain. A diagram is not required. Your description should include the parts of the ear called the ear drum, the oval window, the cochlea, the basilar membrane and the auditory nerve.

14 What is meant by the 'frequency' of a vibration? Describe an experiment to show that the pitch of a sound rises as the frequency of the vibration which causes it increases.

15 Explain very briefly how we hear sounds of different pitch. What feature of light does pitch in sound correspond to?

5

Support and Movement

1. The idea of a force

What weight can you lift? You may be able to lift one of your friends. A weightlifter could lift 200 kg. A small child may have difficulty lifting a large dictionary. In each of the following cases compare the forces mentioned. Is the first force 10 times, 20 times, 100 times, 1000 times etc. greater than the second? The answers will be given at the end of the list. See how close you came to the truth.

(i) The pull exerted by a car on a caravan, and the pull exerted by a small child on a toy car attached to a string.

(ii) The push exerted by a bulldozer on a pile of rubble, and the push exerted by a broom on a pile of rubbish.

(iii) The thrust or push exerted by the hot, compressed gases in a Saturn rocket engine, and the push of the compressed air in a balloon which is blown up and released (see Fig. 5.1).

(iv) The stretching of the spring in a spring balance when a lock is hung from its end, and the stretching of the same spring by the key of the lock.

(v) The compression exerted by a steamroller on new tarmac just placed on a road, and the force exerted by a knife to spread butter on a slice of bread.

(vi) The force exerted by a brick wall when it stops a car travelling at 40 km/hr and the force exerted by the same wall when it stops a bullet travelling at 2 000 km/hr.

In example (i) much would depend on the size and contents of the caravan, but it would not be less than 1 500 kg. and the toy car would weigh about $\frac{1}{4}$ kg, so the first force would be at least 6 000 times the second.

In example (ii) a bulldozer will move about 10 000 kg. while the broom will move about $\frac{1}{2}$ kg. The first force will be 20 000 times greater than the second force.

In example (iii), the Saturn rocket has five engines, giving a total lift of $3\frac{1}{2}$ million kg, each engine on its own giving a lift of about 750 000 kg. The balloon would give a lift of about $\frac{1}{10}$ kg. The first force is about 7 500 000 times greater than the second force.

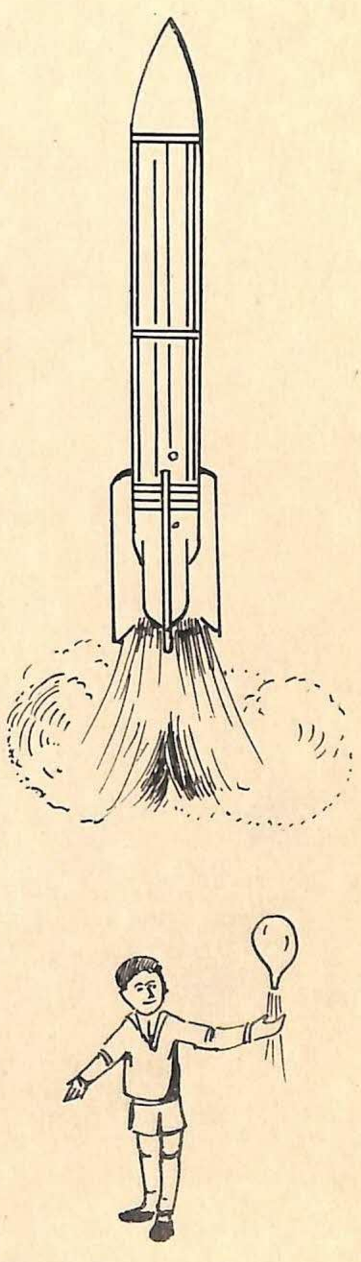


Fig. 5.1 **Rocket and balloon going up due to release of compressed air**

You can find the answer to example (iv) by actually doing the experiment with the lock and key and a spring balance.

In example (v), a car's mass is about 1 000 kg. while that of a bullet is about $\frac{1}{20}$ kg. This means that the mass of the car is about 20 000 times greater than the mass of the bullet. But since the bullet is travelling fifty times faster than the car, the first force would be about 400 times greater than the second force.

Some other examples of forces that were mentioned in Chapter 2 are a moving stream of water turning a turbine, wind turning a grindstone, a falling weight driving a peg into the ground, the compressed spring in a toy car driving it forward, a bow string propelling an arrow through the air. These were used as examples of converting energy in some way. They are also examples of forces being exerted by something on something else. In each case decide what is exerting the force, and what is being affected by the force.

Place a steel ball-bearing on the top of a table and exert forces on it in different ways. For example:

(i) push the ball with your finger
(ii) push the ball with a ruler
(iii) direct a jet of water on the ball (e.g. by squeezing a jet of water from a 'squeeze' bottle)
(iv) blow on the ball through a straw
(v) attract the ball with a magnet
(vi) tilt the table.

In each case what happens to the ball to show that a force has been exerted on it?

In the first three cases, the forces applied could be described as *contact forces.* Is case (iv) an example of a contact force? The straw does not touch the ball. Does anything else touch the ball? In case (v) the magnet does not touch the ball. Does anything else touch the ball? Any force which acts on a body without there being any direct contact with the body, can be described as a *force at a distance.* Is case (vi) an example of a 'contact force', or a 'force at a distance'? Only the table touches the ball, and it also touched it before the tilting. What actually makes the ball move? What exerts this force on the ball? Consider each of the forces involved in the examples that were recalled from Chapter 2, and state, with reasons, whether each is a 'contact force' or a 'force at a distance'. For example, in the case of the falling weight driving a peg into the ground, the force which moves the weight is a force at a distance, while the force which moves the peg is a contact force.

Effects of a force

In all the examples described above the force in question made the body move. Can a force have any other effect on a body? Consider that 'force at a distance' which is called the force of gravity. If a body is thrown up into the air, what is the effect of gravity on the body? At first gravity reduces the speed of upward movement of the body, till at a certain height it comes to a complete stop for a moment, and then gravity increases its speed of movement downwards from zero to the same value that it started its upward movement with.

Now can you think of a contact force which can stop the movement of a body? Does a ball which is kicked move along the ground forever? Does something exert a force on it? What do we call this force? What would be the effect of increasing the strength of this force, for example by kicking the ball just as hard along a gravel path? Gravity can slow an object down, and can speed it up. Can this force produce the same effects?

The last paragraph dealt with the contact force called *friction*. This force comes into action whenever one object tries to move over another. Friction is more when the surfaces in contact are rougher, and is less when they are smoother. Friction never makes things start to move or speed up. Friction between solid surfaces is usually reduced by (a) polishing the surfaces, (b) putting grease or oil between the surfaces, (c) replacing sliding actions by rolling actions e.g. instead of dragging a heavy box along the ground, put it on a roller skate and then pull it along.

If you could have a very large horizontal surface where there was no friction at all, what do you think would happen if an object was given a push across the surface? Would it keep moving in the same direction as it started? Let us now think of some examples in which bodies do change the direction in which they are moving. Here are three.

(i) Throw a ball at an angle against a wall. In what direction does the ball bounce off the wall? What effect does the wall have on the ball?

(ii) Place a strong magnet on a table, and roll a steel ball in a straight line near the magnet. What path does the ball take? What effect does the magnet have on the ball?

(iii) Tie a stone to the end of a string and whirl it at a constant speed in a horizontal circle above your head. What causes the stone to keep changing its direction?

To sum up what we have learned up to this point, the effects that may occur when a force is applied to an object are:

1. The object may start to move or stop moving.
2. The object may speed up or slow down.
3. The object may change its direction of movement.

Now consider the effect of a force in compressing a spring, or in stretching a rubber or elastic cord. Has it produced any of the above effects? You would say that the force altered the shape of the spring, or the cord. So a force can change the shape of an object, but this is actually a case of producing a movement, because to change the shape of an object is to move its parts.

Stick two pins near the ends of a rubber eraser, and apply downward forces at each end of the rubber, as shown in Fig. 5.2. Does the shape of the rubber change? Do the pins move?

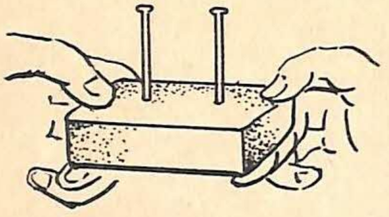


Fig. 5.2 **A rubber, with pins near its edges, being bent by forces at its edges**

Balancing forces

When you push or pull a stationary object does it always start to move? Imagine pushing a bicycle with its brakes released, and then pushing it with its brakes applied hard. Or imagine pulling an empty chair across a floor, and then pulling it with a heavy person sitting on it. Why does the force you apply produce movement in the first case of each example, but not in the second? Would the object move in the second case if pushed or pulled hard enough? This seems to suggest that something was opposing the force in each case; in other words, there was a balancing force. Let us look into this more closely. Fig. 5.3 shows an iron weight at the end of a string. In the first case the other end is in your hand, and in the second it is tied to a hook in the ceiling. In the first case do you have to apply a force to the string to keep the iron weight where it is? Do you think the iron nail does the same thing in the second case? In each case two forces are balancing each other. What are these two forces?

Resultant force

Usually objects are being affected by several forces at the same time. These forces may all balance each other, in which case the object will not start to move. It will only start to move if the forces (including friction) do not balance each other. Any extra force left over when all the remaining forces have been balanced out is called a *resultant force*.

Why is it necessary for the engine of a car to continue to apply force to the wheels to keep the vehicle moving at a steady speed even on a level road? Why must you continue to push on the pedals of a cycle to keep moving steadily along a level road? Some friction force acts on almost every moving object. If no other force acts in the opposite direction to the friction, the moving object will be slowed down by the resultant force of friction. By balancing the friction force with another force, the object can be made to keep moving at the same speed. It continues to move at this speed as long as there is no resultant force to change it.

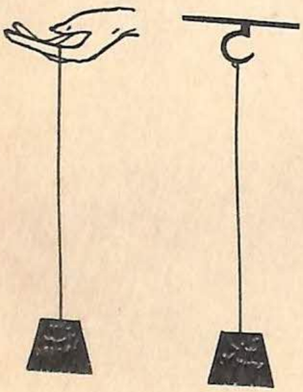


Fig. 5.3 **Iron weight suspended by a string**

Interaction of forces

Let us consider the forces which are exerted when you put this book on the top of a level table. The weight of the book is a downward force, but because the book does not move, there can be no unbalanced forces acting on it. The table top, therefore, must exert an upward force on the book equal to the downward force of the book on the table.

In order to walk forward you must exert a force against the floor with your feet, while the floor pushes against your feet with an equal force in the opposite direction.

In each of these situations we have two objects. In the first case the book and the table top, and in the second case the foot and the floor. Two forces are involved in each situation. In the first, they are the force of the book against the table, and the force of the table against the book. In the second, they are the force of the foot against the floor and the force of the floor against the foot. In such cases, one force may be called the *action*, and the second the *reaction*. Isaac Newton summed up the ideas on the interrelationship of such forces when he said 'for every action there is an equal and opposite reaction'.

We have been considering action and reaction in fixed objects, but Newton's statement is equally true if the objects are free to move. A man rows a boat towards the shore and when he is a metre away from it he leaps ashore. In doing so he exerts a force against the boat, and the boat exerts an equal but opposite force against him. Since both objects are free to move, the man's force against the boat moves it in one direction, while the boat's force against the man moves him in the opposite direction.

Suppose we fasten one spring balance to a fixed support and hook another spring balance to it, as shown in Fig. 5.4. If we pull steadily, we find that both balance readings are the same. The pull of the first balance on the second equals the pull of the second on the first. The action is equal but opposite to the reaction.

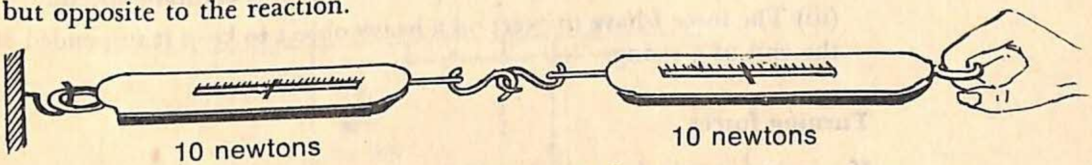


Fig. 5.4 **Two spring balances, hooked together, being pulled apart**

You may think that if action and reaction are equal and opposite, movement will not occur. If two boys pull with equal forces in opposite directions on an object, the object will not move. But this is not an example of action and reaction. There are in this case two balanced forces acting on the same object, whereas action and reaction act on different objects. When a gun shoots out a bullet, the action is the force of the gun on the bullet, while the reaction is the force of the bullet on the gun.

Imagine that you were pulling on a rope fixed to a wall. Is the wall pulling on the other end of the rope? What would happen if the rope were to break while you were pulling on it? Imagine that you were pushing on a swing door that is bolted. Does the door push back on you? What would happen if the door suddenly stopped pushing because someone released the bolt?

Measuring forces

Forces cannot be measured directly; they must be measured by the effects they produce. The effects produced by forces can be summarised as:

(i) changing the movement of bodies,
(ii) changing the shape of bodies i.e. bending or stretching them,
(iii) balancing other forces.

The second effect is the most convenient to deal with. Suppose I use a rubber band. A force that stretches it by 2 cm is double the force that stretches it by 1 cm. If a certain force stretches it by $\frac{1}{2}$ cm it is half that force which stretches it by 1 cm and it is one quarter that force which stretches it by 2 cm. We now begin to see the need for some standard force with which we can compare other forces. The unit in which forces are measured is called the *newton*. The force with which gravity pulls a 1 kg mass is almost 10 newtons (9.8 newtons to be more exact). We can therefore use a spring balance to measure force, changing the readings 1 kg, 2 kg, 3 kg, etc. to 10 newtons, 20 newtons, 30 newtons etc. If the spring balance is marked in gm we can mark it in fractions of a newton remembering that the pull of gravity on a mass of one gm is $\frac{1}{100}$ newton or .01 newtons.

Draw diagrams to show how you would use a spring balance to measure

(i) The force with which a child pulls a toy car attached to a string.

(ii) The force of friction between a book and your desk as you pull the book along the desk. (Remember we said earlier, in the section on 'Balancing Forces', that by balancing the opposing friction force with another force we can keep an object moving at a constant speed).

(iii) The force I have to exert on a heavy object to keep it suspended at the end of a string.

Turning forces

If a force is applied to a body which is fixed at a point, the force will not be able to move the entire body through any distance, but will turn the body about its fixed point. The turning effect that the force will exert on

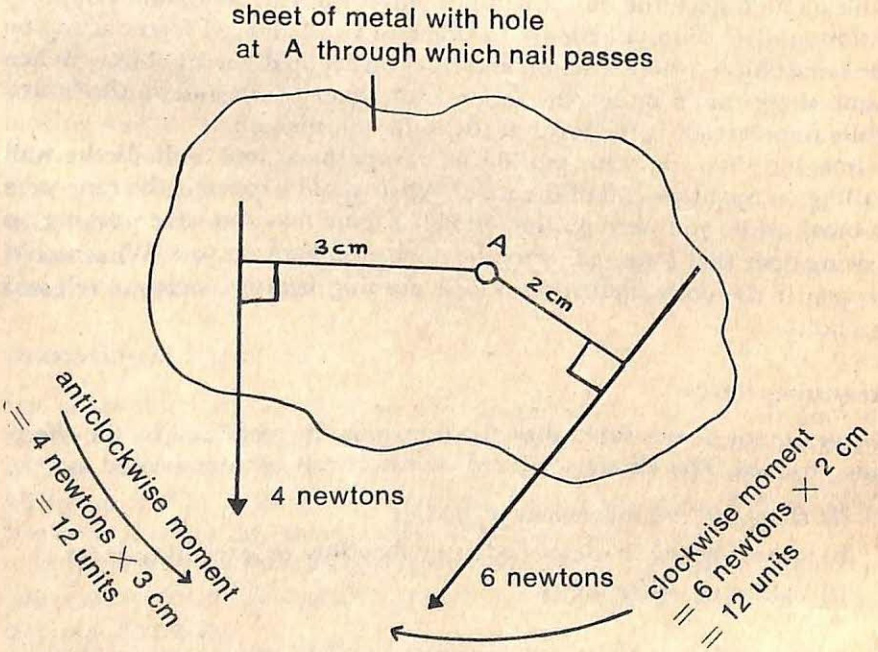
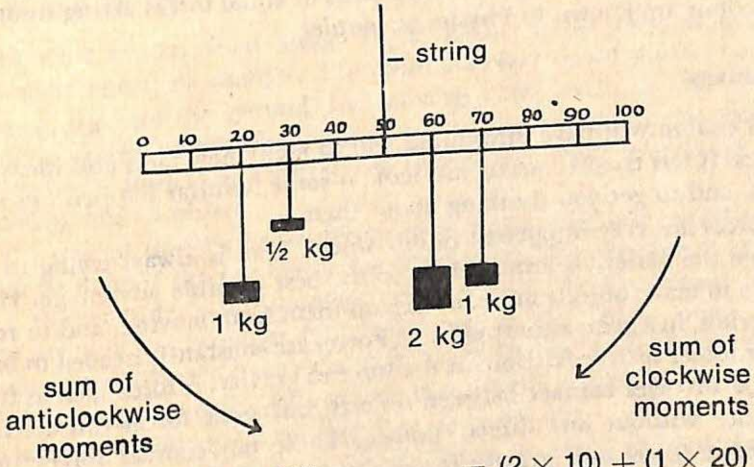


Fig. 5.5 **Illustrating the principle of moments with two forces acting on a body**

the body depends not only on how strong the force is, but also on where it is applied. Where do you get greater turning effect on a door, by pushing closer to the hinges or farther away from them? How can a smaller child balance a bigger person when sitting on opposite sides of a seesaw? The turning effect is actually measured by the product of the strength of the turning force and its perpendicular distance from the fixed point. This product is called the *moment* of the force. Look at Fig. 5.5. The body does not turn because the *moments* or turning effects of the two forces are equal and opposite.

Look at Fig. 5.6. The body does not turn because the moments, or turning effects, in the clockwise direction are equal to those in the anti-clockwise direction, and so balance them. This is known as the *principle of moments.*



sum of anticlockwise moments $= (1 \times 30) + (\frac{1}{2} \times 20)$
$= 30 + 10$
$= 40$ units

sum of clockwise moments $= (2 \times 10) + (1 \times 20)$
$= 20 + 20$
$= 40$ units

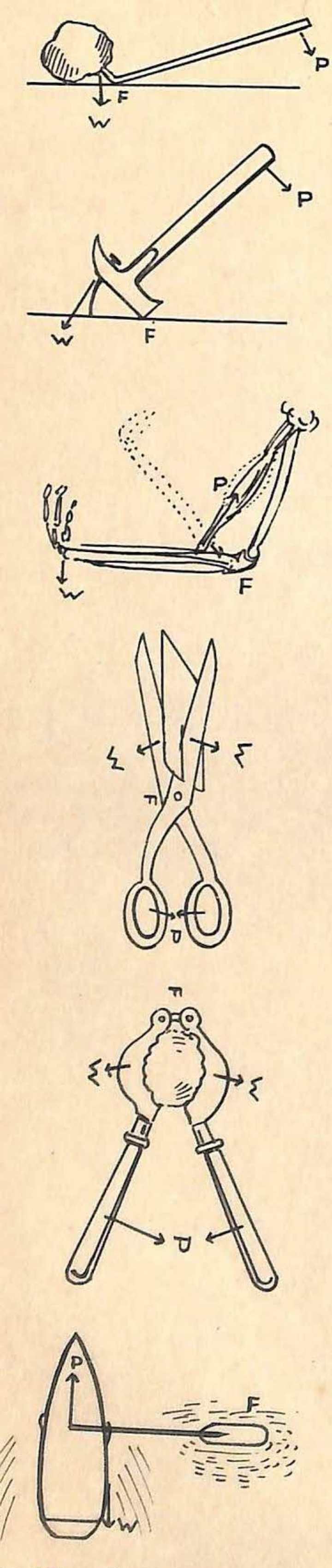
Fig. 5.6 **Illustrating the principle of moments on a metre stick**

Try these simple problems on moments:

1. A child weighing 15 kg balances a man weighing 60 kg sitting on the other side of a seesaw. The man sits 1 metre from the pivot of the seesaw. How far from the pivot does the child sit?
2. A rod weighing 40 g is 20 cm long and its weight acts at its middle point. It is pivoted at one end. What vertical force must be applied at the other end to keep the rod in a horizontal position? What is the direction of this force?

The lever

The fact that a child weighing 15 kg can balance a man weighing 60 kg shows that a smaller force can be multiplied into a larger force, if applied at a greater distance away from the point about which the body can turn.



ig. 5.7 **Some common levers**

This principle, which is really the principle of moments stated differently, is utilised in the machine known as the *lever*. Fig. 5.7 shows some common levers. In each case decide which is the smaller force, and which is the larger force it is being multiplied into, and examine carefully the distance of each of these forces from the turning point which is called the pivot, or the *fulcrum*, of the lever.

Pairs of forces

When a driver turns the steering wheel of a car, one hand moves one end of the wheel up with a force, and the other hand moves the other end down with an equal force. Examples of similar pairs of forces that produce a turning effect are those applied when turning a screwdriver, a corkscrew, and a water tap. (see Fig. 5.8). Such pairs of equal forces acting in opposite directions are known in Physics as *couples*.

Summary

This section will have introduced you to many new facts and ideas about forces. It has tried to make you look at some familiar happenings in new ways, and to get you thinking about them.

Forces are very important in our world. Man is always trying to manipulate the materials around him to the best possible advantage. He uses forces to make objects move, or to stop them from moving, and to reshape materials, in a great variety of ways. Forces are constantly needed to balance other forces such as friction, or the force of gravity. A force such as friction always involves contact between objects, but some forces can act from a distance without any direct contact. These non-contact forces include magnetic forces and gravity forces. Forces can take the form of lifting, pulling, pushing, stretching, compressing or turning.

Forces may produce several different effects. These include:

(i) Making objects start to move or stop moving.

(ii) Making objects speed up or slow down.

(iii) Making objects move in a new direction.

(iv) Changing the size or shape of objects.

(v) Balancing other forces.

When all the forces acting on an object are balanced, there is said to be no resultant force acting on the object. In such a case if the object is stationary, it will stay stationary; if it is moving, it will continue to move in the same direction at the same speed.

For every action there is an equal and opposite reaction. These two equal forces act on different bodies, and so will not produce equal movements if the bodies are not of equal mass.

The unit for measuring force is the newton. The force with which the earth pulls a mass of 1 kg is 9.8 newtons. A spring balance can be used to measure forces in certain cases.

The moment of a force acting on a body fixed at a point measures the turning effect of the force on the body. It is calculated by multiplying the strength of the force (measured, for example, in newtons) by the perpendicular distance of the force from the fixed point in the body. The principle of moments says that if the sum of all the clockwise moments is equal to the sum of all the anti-clockwise moments, the body will not turn in any direction, but will remain at rest.

The lever uses the principle of moments to multiply a small force into a larger one.

'Couples' are pairs of equal, parallel forces which act in opposite directions.

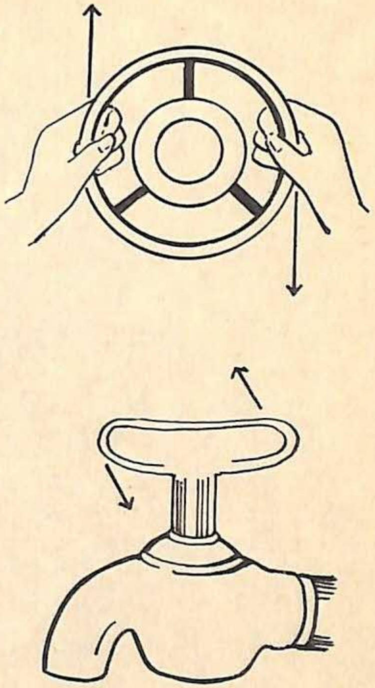


Fig. 5.8 **The turning of a steering wheel and of a tap — examples of 'couples'**

2. Work and Energy

In Chapter 2 we described energy as the 'ability to do work, or to bring about some effect, or change'. The falling weight could do the work of driving a peg into the ground, the moving water could do the work of turning a water wheel, the compressed spring could do the work of shooting out a 'bullet', and a stretched rubber cord could also do the work of shooting out an object.

In the case of the peg being driven into the ground, more work would have to be done if the peg was being driven into harder ground, and less work if the ground was soft. In other words, if the force of resistance offered by the ground was stronger more work would have to be done. Then again more work would have to be done if the peg was to be driven deeper into the ground. To drive it 2 cm into any ground would require twice as much work as to drive it 1 cm into that same ground.

Thus work done involves the magnitude of the force exerted, and the distance through which it is exerted, and is measured by their product. When I lift a brick weighing 1 kg, I must exert a force of 10 newtons (actually 9.8 newtons, but we shall round it off to 10 newtons). If I lift the brick through 2 metres, the work done is

$$10 \text{ newtons} \times 2 \text{ metres} = 20 \text{ newtons} \times \text{metres}.$$

The unit 'newton × metre' is called the *joule*, and so the work done in lifting a brick weighing 1 kg through a height of 2 metres is 20 joules. I must spend 20 joules of energy to do this work. The energy spent is the chemical energy stored in the muscles. It is not lost, for in doing this work 20 joules of potential energy are stored in the body, and this energy can be spent later, for example, in driving a peg into the ground. To pierce into a wooden target a distance of 2 cm against an average resistance of 100 newtons will require work of

$$100 \text{ newtons} \times .02 \text{ metres} = 2 \text{ joules}.$$

The kinetic energy of a moving arrow can do this work. The energy spent reappears as sound and heat energy.

Consider the work done by two forces on each side of a seesaw. A 15 kg child can lift a 60 kg man the other side, but the child must move down through 4 times the distance that the man moves up, as shown in Fig. 5.9.

$$\begin{aligned}\text{Work done by child} &= 150 \text{ newtons} \times 40 \text{ cm}\\ &= 150 \text{ newtons} \times .4 \text{ m}\\ &= 60 \text{ joules.}\\ \text{Work done on man} &= 600 \text{ newtons} \times 10 \text{ cm}\\ &= 600 \text{ newtons} \times .1 \text{ m}\\ &= 60 \text{ joules.}\end{aligned}$$

Thus the work got out is no greater than the work put in, because no more energy can be got out than is put in. The lever is not an energy-multiplier, although it is a force-multiplier.

Machines

Here we shall discuss two common machines.

(i) *The lever*

Fig. 5.9 shows the principle of the lever. Fig. 5.7 showed some common levers. Study the force multiplication in each case, and note that the distance moved by the smaller force is proportionately greater than the distance moved by the greater force, so the energy spent in doing work is the same as the energy realised in the work got out.

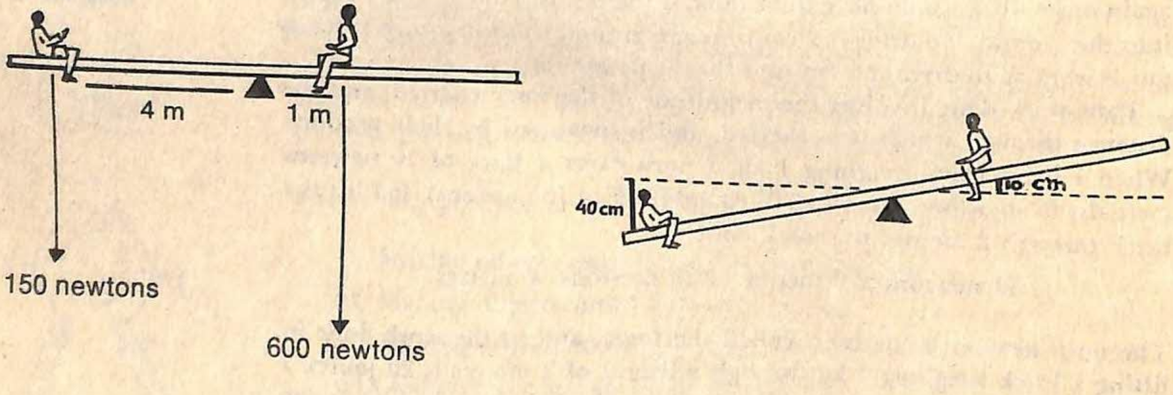


Fig. 5.9 **The principle of the lever**

An interesting example of the lever is the bicep. The anti-clockwise moment of the bicep muscle, represented by a spring balance, is the same as the clockwise moment of the weight being lifted, as shown in Fig. 5.10. The interesting thing to note is that in this lever the force applied by the bicep is not multiplied into a greater one, but into a smaller one. The reason is this. For the force exerted by the bicep to be multiplied into a greater one, the bicep would have to be further away from the elbow joint than the hand which would not be at all convenient or graceful for the human body.

(ii) *The block and tackle*

Fig. 5.11 shows the principle of the block and tackle. Two children hold the rods as shown, and a third child pulls on the end of the string which is passed around the rods as shown. The two children have difficulty keeping the rods apart against the force exerted quite easily by the third child. Just as the string and the rods multiply the force exerted by the third child, the pulleys and the string around them multiply the smaller force exerted so that it can lift a heavier load. Trace the path of the string around the pulleys. Do you see that it is the same as the path of the string around the rods? Try the effect of resisting with the rods the same pull on the string when the string is first wrapped twice around each rod, and then three times around each rod. When is the effect of the pull on the string greater? Which pulley system, the one with two pulleys, or the one with three pulleys, is the better force-multiplier? (see Fig. 5.12).

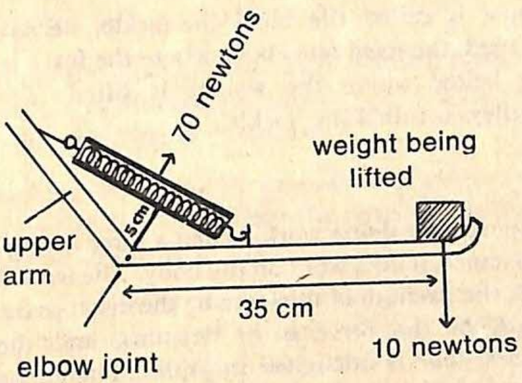


Fig. 5.10 **The bicep as a lever**

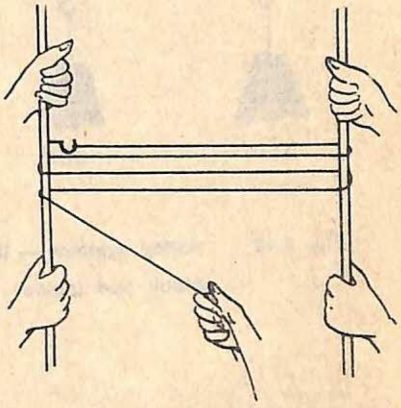


Fig. 5.11 **The principle of the block and tackle**

Calculate by how much each system multiplies the applied force. Remember that whatever force is applied to the end of the string is felt throughout the entire length of the string. If I apply a force of 5 newtons at the end of the string, each strand will exert a 5 newton lifting force on the weight. So if there are four strands, the total lifting force is 20 newtons, and this system will multiply the applied force by four.

Note that the force applied at the end of the string moves through a correspondingly greater distance than the larger force produced to lift the weight, so that no more work is got out than is put in. For example, in the three pulley machine, a force of 5 newtons can produce the force of 30 newtons necessary to lift the 3 kg weight, but this force has to move through 60 cm if the weight is to be raised through 10 cm. This is because if six strands are each to shorten by 10 cm, the total length of string must shorten by 60 cm.

The energy spent in doing the work of pulling on the string = 5 newtons × 60 cm
= 5 newtons × .6 m
= 3 joules.

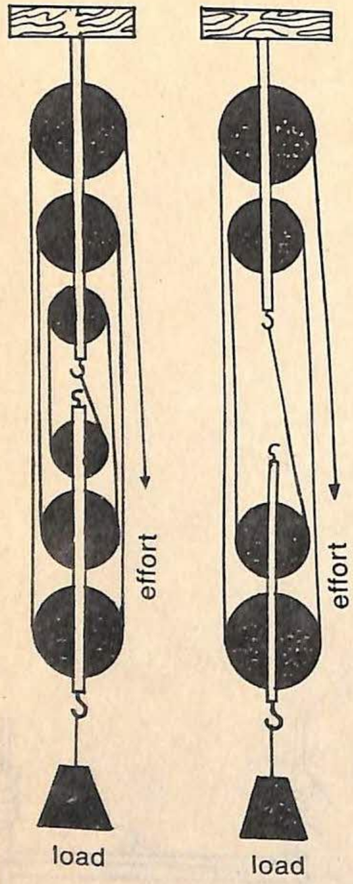


Fig. 5.12 **Pulley systems — the block and tackle**

The energy got out in doing the work of lifting the load = 30 newtons × 10 cm
= 30 newtons × .1 m
= 3 joules.

This machine is called the block-and-tackle, because there are two pulley blocks used, the fixed one above where the force is applied, and the movable one below where the weight is lifted. The string passing around the pulleys is called the 'tackle'.

Summary

Energy is a capacity for doing work. When a force acting on a body moves it through a distance, it does work on the body. The work done is calculated by multiplying the strength of the force by the distance moved by the body. If the strength of the force is in newtons, and the distance is in metres, the work done is calculated in joules. The energy spent in doing work is also measured in joules. Thus a body with 20 joules of energy can do 20 joules of work with that energy.

Machines are force multipliers, but not energy multipliers.

The lever is a common machine which uses the principle of moments. In most levers the force applied is multiplied into a greater force got out. In exceptional cases like the bicep, the force got out is smaller than the applied force. This is because convenience requires that the distance of the applied force from the fulcrum (the elbow-joint, in this case) should be smaller than the distance of the force got out from the fulcrum i.e. the bicep is closer to the elbow joint than the hand.

The block and tackle is another force-multiplier.

Questions

1 Give one example, in each case, of a force that (*a*) lifts, (*b*) pulls, (*c*) pushes, (*d*) stretches, (*e*) compresses, (*f*) resists.

2 Give two examples of a 'contact force' and two examples of a 'force at a distance'.

3 State four effects that a force can produce, and give one example of a force producing each one of the effects stated.

4 How many ways can you think of in which friction differs from gravity?

5 State three ways by which the friction between two surfaces can be reduced.

6 Can a body move even when there is no resultant force acting on it? Explain with an example.

7 Give two examples in which a body is acted on by two balanced forces; one example in which the body is at rest, and one example in which the body is moving.

8 'For every action there is an equal and opposite reaction'. Give three examples of this, and in each example state exactly on which bodies the action and reaction act.

9 What is the name of the unit in which force is measured? How does it compare with the pull of gravity on a 1 kg mass?

10 What is meant by the 'moment' of a force about a point on a body? State the 'Principle of Moments'. Explain with a diagram how you would verify the principle of moments.

11 Two boys weighing 40 kg and 50 kg wish to balance on a seesaw. If the 40 kg boy sits 2½ metres from the centre, how far from the centre must the 50 kg boy sit?

12 A metre stick is pivoted at the 30 cm mark. A weight of 150 g is attached at the 0 cm mark and a weight of 50 g is attached at the 100 cm mark. What weight must be placed at the 80 cm mark to keep the metre stick horizontal? (Neglect the weight of the metre stick).

13 What is meant by a 'couple'? Give two examples of couples.

14 What is meant by 'work'? In what units is it measured? How much work do I do when I lift a 4 kg weight through a height of 50 cm? How much energy do I spend in doing this work? In what form is this energy stored in the weight, at the end of the operation of lifting it?

15 'A machine is a force-multiplier but not an energy-multiplier'. Explain what this statement means using the example of a lever in which a force of 10 newtons produces a force of 80 newtons. Draw a diagram to show the distances moved by each force, and use the work done by each force to explain your answer.

16 Draw diagrams of two common levers in everyday use.

17 Draw a diagram to show the action of the bicep. Why is it that in this lever the force got out is less than the force put in?

18 Draw a diagram of a block and tackle with two pulleys in each block. Show the path of the string clearly. If a force of 20 newtons is applied, what force will be got out? If the applied force is moved through 10 cm through what height will the load be lifted?

6

Magnetism

Albert Einstein, when he wrote his life story at the age of 67, recalled the day when, as a little boy of four, he was happy because his father had given him a new toy. The toy was a compass needle, and the wonder it aroused remained with Einstein all his life. Most of us have also felt the same wonder, and many of us have, as children, experienced the fascination of a magnet which attracts iron. Quite a few of us have used a magnetic compass needle, and have been intrigued by the fact that it always pointed to the north, no matter how much we turned it around. In this chapter we are going to study some of the simple basic facts of magnetism.

The study of magnetism began in ancient times when the Greeks observed the power of attraction of *lodestone* for iron. Lodestone is the mineral 'magnetite', an oxide of iron, which was found in large quantities in Greece and in Asia Minor. The first deposits of lodestone were found in the city of Magnesia, in Asia Minor – hence the name 'magnetite' was given to the mineral, and from this the names 'magnetism' and 'magnet' have been derived.

1. Properties of a magnet

A piece of magnetite attracts pieces of iron and steel. This is known as its *attractive property.* A piece of magnetite if suspended so that it can turn freely in a horizontal plane, will always come to rest pointing north-and-south. This is known as its *directive property.*

(i) *Natural and Artificial Magnets*

We can make magnets which will have the same two properties. These are known as 'artificial magnets', while pieces of 'magnetite' or 'lodestone' are described as 'natural magnets'. The advantage of such artificial magnets is that they can be made of more convenient size and shape and also much stronger, than natural magnets.

(ii) *Uses of magnets*

Magnets can be put to a variety of uses, which can be classified according to (a) those that arise from their attractive property, (b) those that arise from their directive property, (c) those that arise from the relationship of magnetism to electricity.

The attractive property of magnets has been used for a wide variety of uses from lifting heavy cargo off a ship on to the dock, to delicately drawing metal splinters from an injured eye.

The directive property of magnets is used in the magnetic compass. The Chinese discovered, probably about the eleventh century, that a magnet acts as a compass. The use of natural magnets in navigation gave the mineral magnetite the name 'lodestone', which means 'leading stone'. The mariner's compass is a more elaborate form of the pocket compass shown in Fig. 6.1.

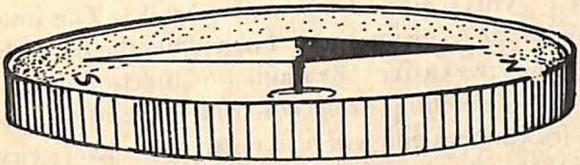


Fig. 6.1 **A pocket compass**

The relationship of magnetism to electricity has led to its use in a great number of machines and appliances, including the huge generators that make electricity, the electric motors such as are used in machines ranging from the electric fan to the electric train, the T.V. sets that delight millions of viewers, and a host of others too numerous to mention, and many of which you will study later in Physics.

For all these uses, artificial magnets are more useful than natural magnets, because they can be made of shapes to suit the requirements of that particular machine or appliance, and can be made very powerful and long lasting.

(iii) *Poles of a bar magnet*

If a bar magnet is rolled in iron filings, the filings are seen to be attracted in large clumps around the ends of the magnet (see Fig. 6.2). These points

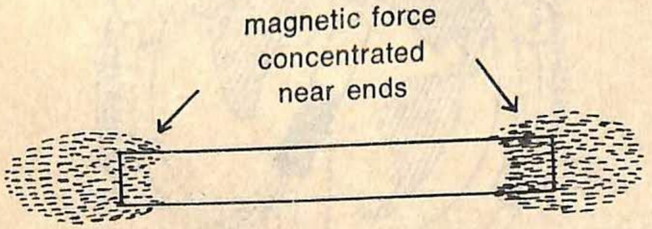


Fig. 6.2 **Poles of a bar magnet**

at which the magnetic force is concentrated are called the *poles* of the magnet. The pole that points towards the geographical north, when the magnet is freely suspended, is called the north-seeking pole or *north pole*, while the pole that points to the geographical south is called the south-seeking pole or *south pole*.

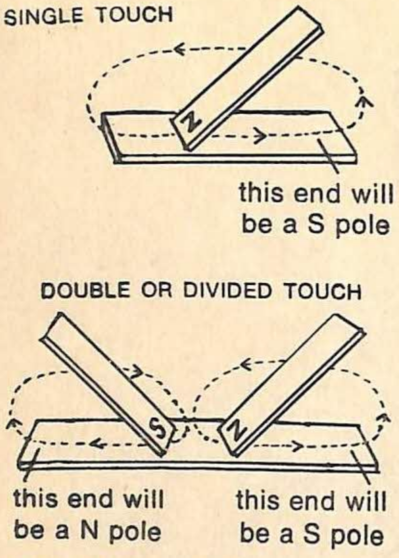

SINGLE TOUCH
N
this end will be a S pole
DOUBLE OR DIVIDED TOUCH
S
N
this end will be a N pole
this end will be a S pole

Fig. 6.3 **Magnetisation by stroking. Single Touch and Double or Divided Touch**

2. Methods of magnetizing and demagnetizing

Since artificial magnets are more suitable than natural magnets for the many uses outlined above, they are made in large numbers. There are two methods of magnetizing a piece of iron or steel. The first is by stroking it with another magnet. This is shown in Fig. 6.3. There are two ways of stroking, the Single Touch method and the Divided Touch method. In each case the stroking should be in one direction and not back and forth. The end where the stroking pole leaves off will be of opposite polarity to the stroking pole. The second, and by far the more useful one, is by using electric current. This method is shown in Fig. 6.4. The resulting polarity can be known by the following rule: 'Look along the bar to be magnetized, in the direction of the current. Examine the direction of the coiling at the end near you; if the coiling is clockwise that end will be a south pole, and if it is anticlockwise that end will be a north pole'. Every electric cell has a positive terminal and a negative terminal, and the direction of the current it provides is from the positive terminal to the negative terminal. In a dry cell, such as we use in a torchlight, the small brass head is the positive terminal and the outer zinc container is the negative terminal.

There are two simple methods by which a magnet can be demagnetized. The first is by rough handling. If you hit a magnet repeatedly with a hammer or drop it down a few times, it will lose its magnetic power. The other method is by heating it. As it gets hotter and hotter it gradually loses its magnetic power, till at a certain temperature it completely loses its magnetism.

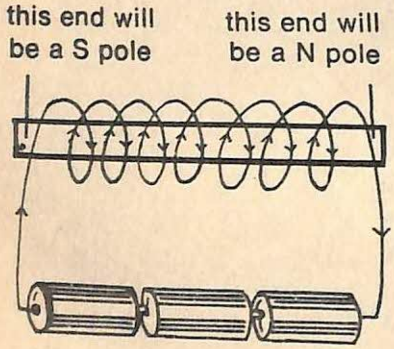


Fig. 6.4 **Magnetisation by an electric current**

3. The Earth as a magnet

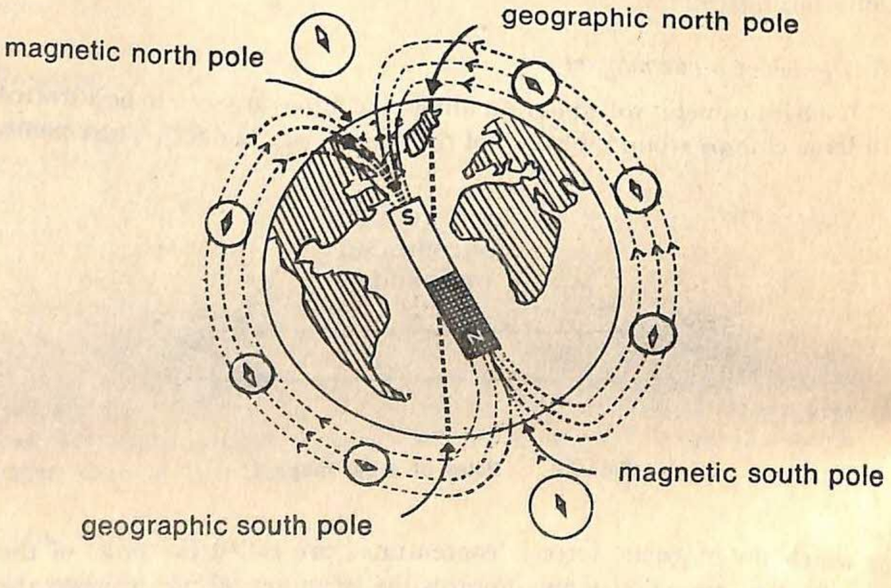


Fig. 6.5 **The Earth as a magnet**

Why does a magnet always point north-and-south? The answer is that the earth itself is a huge magnet, with a magnetic south pole situated near the geographical North Pole, and with a magnetic north pole near the geographical South Pole. Fig. 6.5 shows this, and shows the direction a magnet would take if suspended freely at any point on the earth's surface. The shaded point of the small magnet is its north pole. The earth magnet attracts any magnet. The south pole of the earth magnet pulls the north pole of the small magnet, and the north pole of the earth magnet pulls the south pole of the small magnet. This is because when two magnets are brought near each other *like poles repel each other and unlike poles attract each other*.

Declination

A freely suspended magnet at most places does not point exactly geographical north-and-south. This is because, as Fig. 6.5 shows, the earth magnet does not lie exactly along the earth's geographical north-and-south axis. The angle between the direction of a magnet, freely suspended at any place, and the earth's geographical north-and-south axis, is called the *declination* of that place. (see Fig. 6.6). Will a compass needle point to the geographical north? Why is a knowledge of the declination at any place essential for accurate navigation?

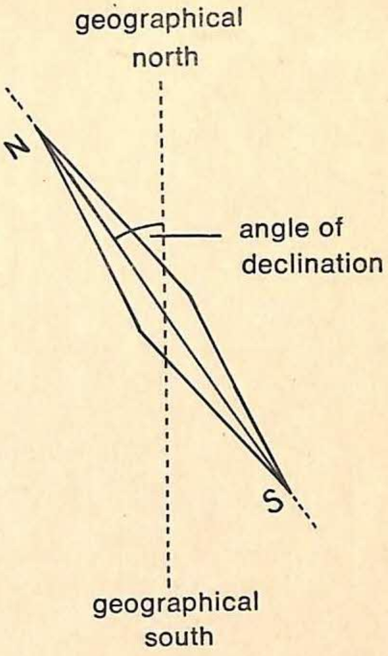
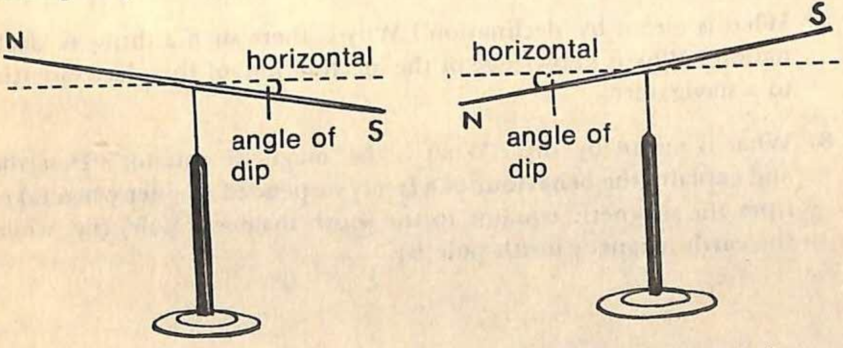


Fig. 6.6 **Angle of 'declination'**

Dip

In the northern hemisphere, a freely suspended magnet is closer to the earth magnet's south pole and farther from the earth magnet's north pole. This means that the small magnet's north pole will be attracted more by the earth magnet's south pole than its south pole is attracted by the earth magnet's north pole, and this will cause the magnet to *dip* down with its north pole pointing downwards.



In the Southern Hemisphere In the Northern Hemisphere

Fig. 6.7 **Angle of 'dip'**

If a magnet is freely suspended in the southern hemisphere which of the earth magnet's poles is it closer to and from which is it farther away? Which pole of the small magnet will be more affected by the earth magnet? Which way will the small magnet dip?

The dip of a magnet is shown in Fig. 6.7. If a magnet is suspended freely and is thoroughly horizontal, then its poles are equally affected by the earth magnet poles and must be equidistant from them. An imaginary line connecting all points on the earth's surface where a freely suspended magnet would be horizontal is known as the *magnetic equator*. If a freely suspended magnet was gradually moved from the magnetic equator to the magnetic north pole (i.e. where the south pole of the earth magnet is), the north pole of the magnet would keep dipping lower and lower down, till at the magnetic north pole it would be vertical with its north pole pointing straight into the ground.

Questions

1 What is a natural magnet? What are the two names for natural magnets? Explain the origin of each name.

2 What is meant by the 'attractive property' and the 'directive property' of a magnet. State one use for magnets deriving from each of these properties.

3 Why are artificial magnets preferred to natural magnets?

4 What are the 'poles' of a bar magnet? Why are they called 'north pole' and 'south pole'?

5 Describe, with a diagram in each case, two ways by which you could magnetize a steel knitting needle so that its pointed end would be a north pole.

6 Describe two ways by which you could demagnetize a magnet.

7 What is meant by 'declination'? Why is there such a thing as 'declination'? Why is knowledge of the 'declination' of the place essential to a navigator?

8 What is meant by 'dip'? What is the 'magnetic equator'? Describe, and explain, the behaviour of a freely suspended magnet when taken from the magnetic equator to the south magnetic pole (i.e. where the earth magnet's north pole is).

7

Electricity

1. Electricity at rest

ALL of you are familiar with many devices operated by electricity, which can be started or stopped with the flick of a switch. These are examples of electricity in motion, a comparatively recent scientific development. Early experiments were limited to electricity at rest, or *static electricity*. The discovery of electricity is generally attributed to Thales (pronounced 'thay – leez') of Miletus, one of the seven wise men of Greece, about 600 B.C. He learned that amber (a yellowish fossilized resin), when rubbed with wool, attracted light objects like wood shavings. Centuries later, William Gilbert (1540-1603), an English scientist, discovered that many kinds of materials behave like amber i.e. when rubbed, they acquire the ability to attract light objects. Gilbert is credited with giving the name *electricity* (from the Greek word for amber, 'elektron') to this property of matter. The science of electricity began to develop from the beginning of the seventeenth century. The study of static electricity, or *electrostatics* as it is also called, paved the way for advancement in current electricity or electricity in motion.

2. Charging by friction

As mentioned above the phenomenon of charging amber by friction was first noted over 2 500 years ago. However similar discoveries have been made by almost everyone at some time or other. You yourself have probably been fascinated to discover that on a cold dry day a comb that has been run through your hair a few times will pick up bits of paper. Some of you might have rubbed a cat's back and heard its hair crackle. Those who live in colder climates and use rugs and carpets on the floor, might be startled by a shock when, after scuffing across a dry wool carpet, they touch another person or a metallic object like a door-knob. It has been calculated that by the method last mentioned, walking across a dry wool rug, as much as 30 000 volts of electricity can be generated on the body of a person with a very dry skin.

Materials that have gained the property of attracting small bits of paper and other light objects are said to have an *electric charge*. Substances that do not have such a charge are said to be *neutral*. It has been found that whenever two different substances are rubbed together each will become electrically charged. Responsibility for many fires has been traced to charges of static electricity.

An interesting case of charging by friction occurs when a motor car is travelling along. The air rushing past the metal body of the car causes it to become charged by friction. If the tyres do not let this charge leak away to the earth, when the motor car stops, the body of a person stepping out of the motor car produces a path along which the electric charge moves to the earth. Severe shocks have been experienced because of this. The danger becomes more pronounced when a spark due to such electrical charge may ignite any inflammable material being carried, like petrol. One way of avoiding the danger is to have a metal chain dragging along the ground by which the charge, building up by friction on the body of the vehicle (a petrol truck for example), can leak away to the earth. The chain provides a conducting path for the charge to keep leaking away, and so it does not build up on the body of the vehicle. Another method being used nowadays is to introduce a carbon compound into the materials of the tyres of vehicles, which makes the tyres able to conduct the charge away to the earth, so there is no pile-up of charge on the body of the vehicle.

The famous airship, the 'Hindenburg', was probably destroyed because of charging by friction. The 'Hindenburg', built in Germany in 1936, was the first aircraft to carry passengers for a fare across the Atlantic. It was 245 m long, cigar-shaped, and its length was divided into a series of separate compartments in which were large bags filled with hydrogen. Hydrogen gas is the lightest gas known, and gave the Hindenburg its lifting power. Fifty passengers were accommodated in a carriage fitted under the airship. It had made ten successful trips from Europe to America when, on the 6th of May 1937, coming in to land at Lakehurst, New Jersey, a sudden spark caused by the leaking away of the strong electrical charge built up by friction on the very large surface area of the airship, occurred in the vicinity of a hydrogen leak. Hydrogen being inflammable, the airship burst into flame and was completely destroyed with the loss of thirty-six lives.

Gramophone records tend to become covered with dust very easily. As the record moves around and around on the player it becomes charged by friction with the air, and small dust particles in the air near the record are attracted to it. These dust particles affect correct sound production by the record as they cause surface noise.

3. Two types of charge; no third type

The presence of an electrostatic charge may be observed by using an *electroscope*. The simplest kind of electroscope is a small ball of wood pith suspended by a silk thread. This electroscope is more sensitive if the pith ball is coated with aluminium or graphite. Suppose a rod of hard rubber or of ebonite or plastic (e.g. a plastic fountain pen) is charged by rubbing it with flannel or fur. If the end of the charged rod is then held

near a simple electroscope, the pith ball is attracted to the rod, as shown in Fig. 7.1.

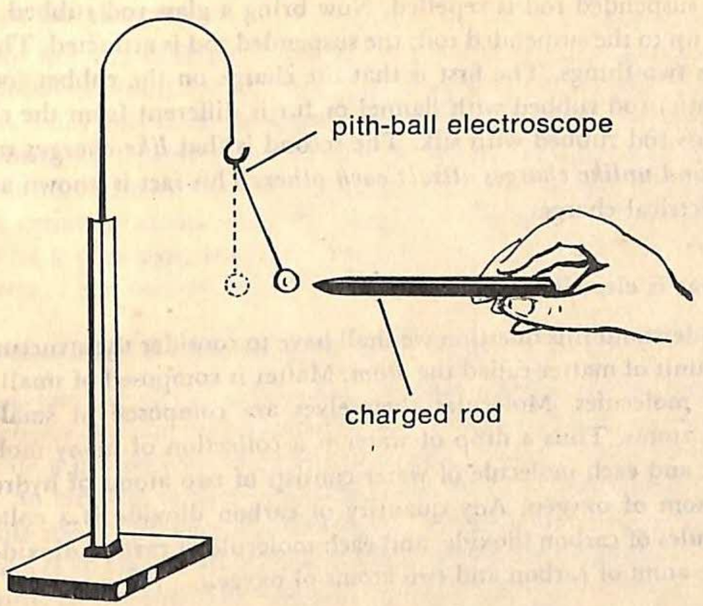


Fig. 7.1 **Pithball electroscope**

If the pith ball is allowed to come in contact with the charged rod it is then repelled by the rod. We may reasonably assume that when the pith ball touched the charged rod some of the charge on the rod was transferred to the pith ball so that both the ball and the rod are now similarly charged.

Suppose a glass rod is charged by rubbing it with silk. If the glass rod is held near the charged pith ball, it is attracted rather than repelled as it was with the charged rubber (or ebonite or plastic) rod. This would suggest that the charge on the glass rod is different from the charge on the other rod because it attracts the charged pith ball while the other repelled it.

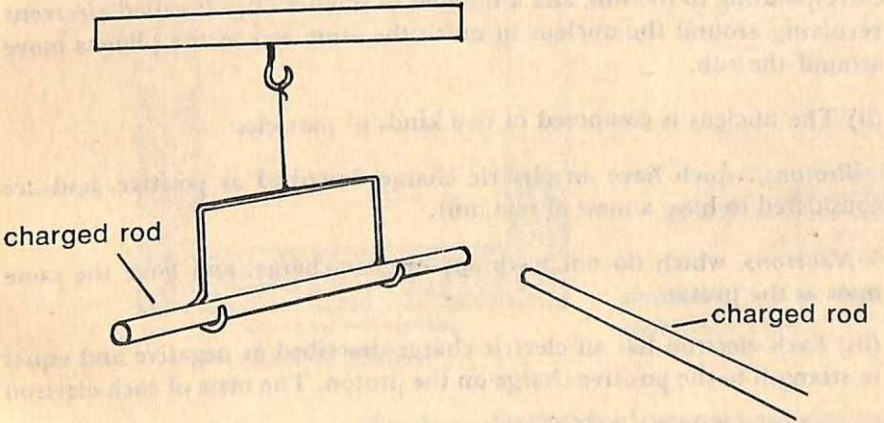
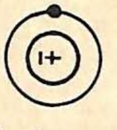


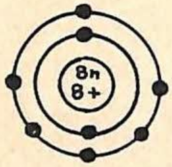
Fig. 7.2 **Attraction and repulsion of electrostatic changes**

Charge an ebonite (or rubber or plastic) rod by rubbing it with flannel or fur, and suspend it by a stirrup hanging from a silk thread as shown in

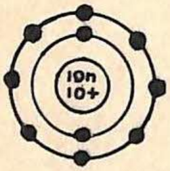
Fig. 7.2. Bring another similar rod charged in the same way slowly up to it; the suspended rod is repelled. Now bring a glass rod rubbed with silk slowly up to the suspended rod; the suspended rod is attracted. This clearly tells us two things. The first is that the charge on the rubber (or ebonite or plastic) rod rubbed with flannel or fur is different from the charge on the glass rod rubbed with silk. The second is that *like charges repel each other and unlike charges attract each other*. This fact is known as the law for electrical charges.



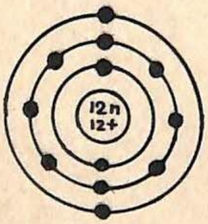
hydrogen



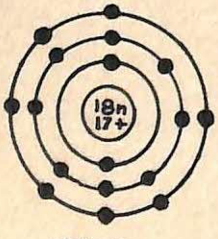
oxygen



neon



magnesium



chlorine

Fig. 7.3 **Structure of some common atoms**

4. What is electricity?

To understand this question we shall have to consider the structure of that small unit of matter called the *atom*. Matter is composed of small particles called molecules. Molecules themselves are composed of smaller units called atoms. Thus a drop of water is a collection of many molecules of water, and each molecule of water consists of two atoms of hydrogen and one atom of oxygen. Any quantity of carbon dioxide is a collection of molecules of carbon dioxide, and each molecule of carbon dioxide consists of one atom of carbon and two atoms of oxygen.

The structure of the atom. Our knowledge of the *structure* of matter has made great progress since the beginning of this century. Much experimental work has been done, much evidence has been collected, and all the information so obtained has led to the modern concept of the atom, which is quite different from that held at the end of the last century. Until that time the atom was thought to be the smallest particle of matter. Since then our knowledge of the structure of the atom has increased considerably, and we now have very detailed knowledge of it. As much of this knowledge as is necessary for us at this stage is summarised below.

(i) The atom may be pictured as a miniature solar system with most of the mass of the atom concentrated in a central mass called the *nucleus*, corresponding to the sun, and a number of smaller objects called *electrons* revolving around the nucleus in much the same way as the planets move around the sun.

(ii) The nucleus is composed of two kinds of particles:

Protons, which have an electric charge described as positive, and are considered to have a mass of one unit.

Neutrons, which do not have any electric charge, and have the same mass as the proton.

(iii) Each electron has an electric charge described as negative and equal in strength to the positive charge on the proton. The mass of each electron is approximately $\frac{1}{1840}$ of the mass of a proton.

(iv) In any atom the number of electrons is the same as the number of protons. Therefore atoms are normally neutral, since the total positive charge of the protons is exactly counterbalanced by the total negative charge on the electrons.

(v) There are 105 different kinds of atoms known at the present time. These different atoms are all composed of similar protons, neutrons and electrons. They only differ in the number of these. For instance, a hydrogen atom consists of 1 proton and 1 electron, while an oxygen atom consists of 8 protons, 8 neutrons and 8 electrons. Fig. 7.3 shows the structure of some common atoms. The electrons are denoted by black dots, the protons by a plus sign, and the neutrons by 'n'. Note that the electrons circle around the nucleus in different paths or *orbits*.

5. Explanation of electric charge and of charging by friction

An understanding of the structure of the atom enables us to understand why an object becomes charged by friction. Tremendous forces are required to separate a proton from the nucleus of an atom, but it is relatively easy to cause an electron to leave an atom or to move to another atom. When an ebonite rod is rubbed with flannel or fur, electrons are transferred from the flannel or the fur to the ebonite. Since electrons carry a negative charge, the ebonite, on gaining electrons, gains a negative charge, while the flannel or fur, on losing electrons, now has a larger number of protons than electrons in the sum total of its atoms, and so has a positive charge. Similarly, when a glass rod is rubbed with silk, electrons are rubbed off on to the silk. The glass rod, losing electrons, becomes positively charged, and the silk, gaining electrons, becomes negatively charged.

We may now *define a positive charge as a deficiency of electrons, and a negative charge as a surplus of electrons. A neutral body has equal numbers of protons and electrons.*

The act of charging a body by friction consists in rubbing electrons off or onto that body.

6. Electricity in motion: the electric current

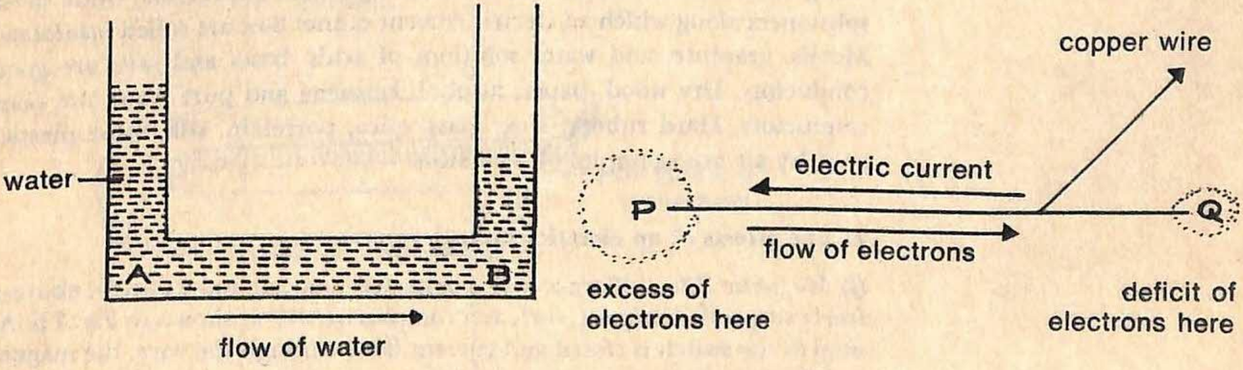


Fig. 7.4 **Electron flow compared to water flow**

Consider the arrangement shown in Fig. 7.4. Water will flow from A to B as long as the height of water above A is greater than the height of water above B, and the flow of water will stop as soon as the levels of water above A and B become the same. Similarly electrons will flow along a copper wire from P to Q if there is a surplus of electrons at P and a deficit of electrons at Q, and the flow of electrons from P to Q will stop as soon as the concentration of electrons at P becomes equal to the concentration of electrons at Q. *The flow of electrons from P to Q is* what we describe as *an electric current*, except, for reasons that shall be explained later, we say that the electric current flows *from Q to P.*

The greater the difference in height of water in the two limbs of the tube the stronger will be the flow of water from A to B. Similarly the more pronounced the difference in concentration of electrons at P and Q, the stronger will be the electron flow from P to Q i.e. the stronger the electric current from Q to P. Thus a slight excess of electrons at P and a slight deficit of electrons at Q, would cause a weak electron flow from P to Q and therefore a weak current from Q to P, while a large excess of electrons at P and a great deficit of electrons at Q would cause a strong electron flow from P to Q and therefore a strong current from Q to P.

It is easy to understand why the electrons flow from where there are too many of them to where there are too few of them, if one remembers that like charges repel each other. Electrons, all carrying the same negative charge, repel each other, and so if there is an excess of them they will repel each other strongly, and some will be repelled towards the area where there is a scarcity of electrons and from which they will not be repelled back so strongly.

To keep an electric current flowing, i.e. to keep the electrons flowing from any one point to any other for any length of time, it is necessary to maintain an excess of electrons at one point and a deficit of electrons at the other. You will learn later how this is done by electric cells, such as the torch cell, or by the electric mains supply at every electric socket in a building.

An electric current cannot flow along every substance. Those substances along which an electric current can flow are called *conductors*, while those substances along which an electric current cannot flow are called *insulators*. Metals, graphite, and water solutions of acids, bases and salts are good conductors. Dry wood, paper, alcohol, kerosene and pure water are poor conductors. Hard rubber, wax, glass, mica, porcelain, silk, some plastics and dry air are examples of insulators.

7. The effects of an electric current

(i) *Magnetic Effect.* Place a wire, connected to a cell and a switch, above a freely suspended magnet, such as a compass needle, as shown in Fig. 7.5. As soon as the switch is closed and current flows through the wire, the magnet is deflected. This shows that an electric current has a magnetic effect. It is this magnetic effect of an electric current that was used to magnetize a piece of iron as described in Chapter 6 (see Fig. 6.4). A magnet produced in this way is known as an *electromagnet*. It can be made very powerful and has a great many uses ranging from lifting heavy objects like cargo from a ship or light objects like metal splinters from an eye. Electromagnets are essential parts of electric motors and electric generators, and we shall study this use of them in greater detail later in our Physics Course.

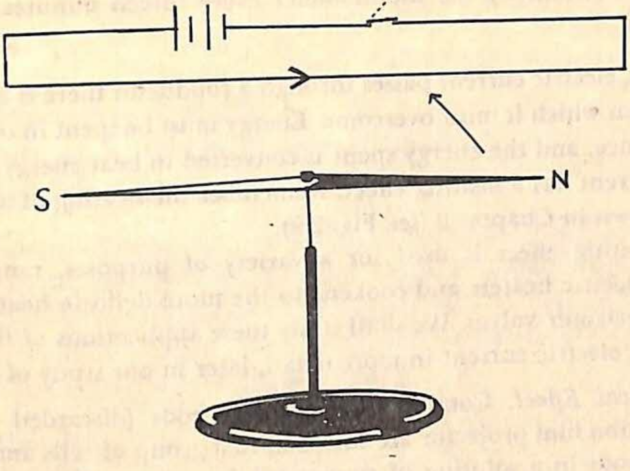


Fig. 7.5 **Magnetic effect of an electric current**

(ii) *Mechanical Effect*. Place a vertical wire, connected to a cell and a switch, between the poles of a horse-shoe magnet, as shown in Fig. 7.6. As soon as the switch is closed and the current flows, the wire moves. This shows that there is a mechanical force exerted on a current-carrying conductor placed between the poles of a magnet. This mechanical effect is put to many uses, and later in your study of Physics you will learn how it is used in the construction of an electric motor. Such a motor can be used to work many machines ranging from electric fans and electric mixers to electric trains and tram-cars. This mechanical effect is also used for electrical measurements in instruments called Galvanometers, Ammeters and Voltmeters.

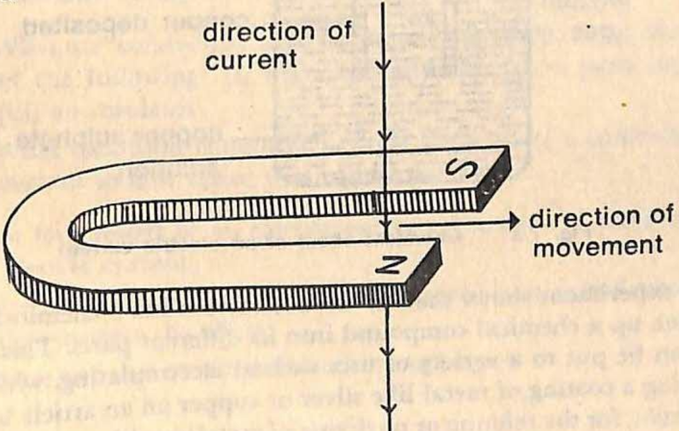


Fig. 7.6 **Mechanical effect of an electric current**

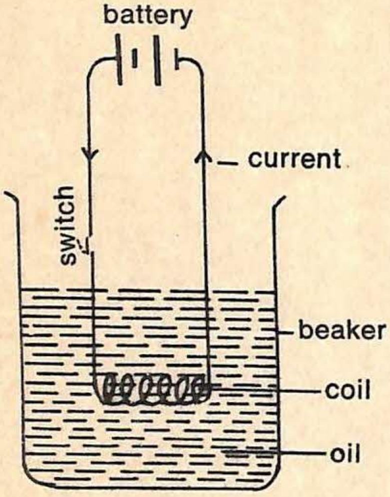


Fig. 7.7 **Heating effect of an electric current**

(iii) *Heating Effect.* Place a coil of wire, connected to a group of cells and a switch, in some oil placed in a beaker, as shown in Fig. 7.7. Read the temperature shown by the thermometer, and close the switch. Take the temperature shown by the thermometer every fifteen minutes. What do you notice?

When an electric current passes through a conductor there is a resistance to its motion which it must overcome. Energy must be spent in overcoming this resistance, and the energy spent is converted to heat energy. Thus the electric current has a heating effect. Remember the heating of a resistance wire as shown in Chapter 2 (see Fig. 2.9).

This heating effect is used for a variety of purposes, ranging from domestic electric heaters and cookers, to the more delicate heating of the wires in electronic valves. We shall study these applications of the heating effect of an electric current in more detail, later in our study of Physics.

(iv) *Chemical Effect.* Connect two graphite rods (discarded electrodes from a motion film projector are suitable) to a group of cells and a switch. Put these rods in a solution of copper sulphate in a beaker as shown in Fig. 7.8. Close the switch, and as the current passes through the solution, copper will be deposited on the rod connected to the negative end of the battery (a group of cells is called a *battery*), and oxygen gas will be given off at that rod which is connected to the positive end of the battery.

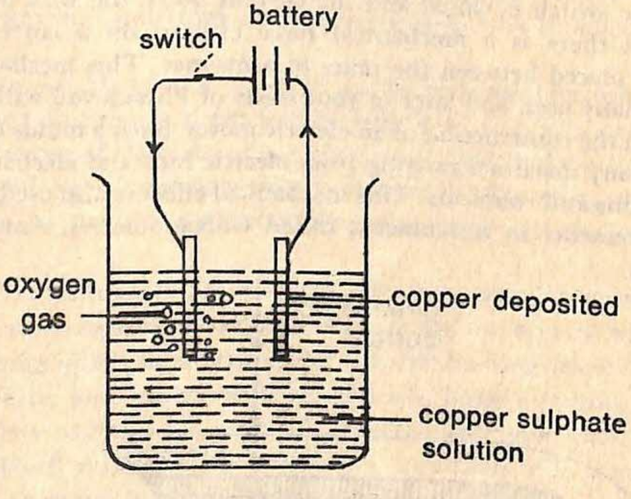


Fig. 7.8 **Chemical effect of an electric current**

This experiment shows that an electric current has a chemical effect. It can break up a chemical compound into its different parts. This chemical effect can be put to a variety of uses such as electroplating, which means depositing a coating of metal like silver or copper on an article by an electric current, for the refining or purifying of metals, and for the extraction of some metals from their ores. Electric cells like the torch cell are applications of the chemical effect of an electric current, and you may be interested to learn that gramophone records are made by a process which is similar to the experiment described above.

We shall study more about the chemical effects of an electric current later in our study of both Physics and Chemistry.

Questions

1 **a** Define static electricity.
 b How can an electric charge be produced?
 c How is it detected?

2 **a** How would you show by experiments that the electric charge on ebonite produced by rubbing it with fur or flannel is different from the charge produced on a glass rod by rubbing it with silk? How many different kinds of electric charge are there?
 b State the law for electrical charges.

3 **a** Describe in point form our modern concept of the structure of the atom.
 b In terms of the electron theory, what is (i) a positively charged body, (ii) a negatively charged body, (iii) a neutral body?
 c Why does (i) ebonite become negatively charged when rubbed with wool, (ii) glass become positively charged when rubbed with silk? What is the electrical condition of the wool and the silk after the rubbing?

4 **a** For what purposes is an electroscope used?
 b Describe and explain what happens when first a positively charged and then a negatively charged body, is brought up to an uncharged pithball electroscope.
 c How would you use a pith ball electroscope to identify an unknown charge?

5 **a** What are 'conductors' and 'insulators'? Give two examples of each of the following: (i) a good conductor, (ii) a poor conductor, (iii) an insulator.
 b What condition is necessary across the ends of a conductor for a current to flow across that conductor?

6 State four effects of an electric current. For each of these effects of an electric current:
 a describe with a diagram, an experiment you would perform to demonstrate the effect;
 b State two uses to which the effect can be put.

Part 2

FOR CLASS 8

INSTITUTE OF EDUCATION FOR WOMEN,
Deptt. of Extension Services.
CALCUTTA-27

8

More About Force, Movement and Machines

In Chapter 5 we described different types of forces and studied their effects. We learned that forces could be 'contact forces' like pushes, pulls and resistances, or 'forces at a distance' like gravity and magnetic attraction. We also learned that a force applied to an object may

(i) set the object into motion, or bring it to rest,

(ii) alter its speed (this includes the previous effect),

(iii) change the direction of its motion, or

(iv) change its shape or size.

We also learned that forces may balance each other i.e. cancel each other out, or may produce a 'resultant' force. We saw that if one body exerts a force on another, the other will exert an equal and opposite force – a reaction – on the first. We learned also that the turning effect of a force on a body depended on the product of the force and its perpendicular distance from the point about which the body turned, and that this product is called the 'moment' of the force about that point. Finally, we learned that energy was required to do work, that machines like the lever and the block-and-tackle were force-multipliers but not energy-multipliers, and that force is measured in newtons, and energy and work in joules.

In this chapter we shall learn more about force and movement, about energy and work, and machines.

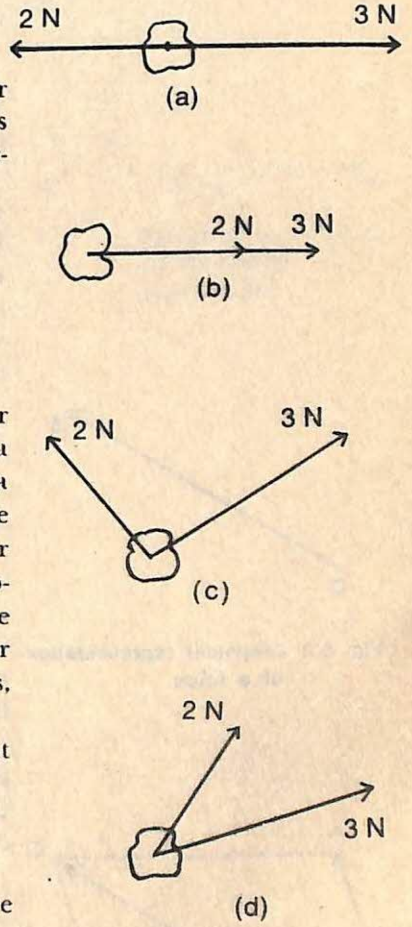


Fig. 8.1 **Forces of 3N and 2N acting at different angles from 0° to 180°**

1. Force is a vector

If you gave a man 3 rupees and I gave him 2 rupees, the man would have received 5 rupees from the two of us – no more, no less.

If you exert a force of 3 newtons on a body, and I simultaneously exert a force of 2 newtons on the same body, must the total effect on the body be a force of 5 newtons – or can it be more or less? Look at Fig. 8.1 and answer this question.

Why is it that the addition of 3 rupees to 2 rupees can only give one answer viz. 5 rupees, but the addition of 3 newtons to 2 newtons can give any answer ranging from 1 newton to 5 newtons? The answer is that the two forces produce different total effects when they act at different angles to each other i.e. when they are in different directions, but the matter of direction does not enter into the addition of 3 rupees to 2 rupees.

Quantities which involve only magnitude are called *scalar* quantities, while a quantity which involves both magnitude and direction, i.e. which is only fully known when both its magnitude and its direction are known, is called a *vector* quantity. A force of 3 newtons acting vertically and a force of 3 newtons acting horizontally are two quite different forces, but 3 rupees is always the same as any other 3 rupees. Length and time are other examples of scalar quantities, while velocity is an example of a vector quantity. 50 km per hour due North is quite a different velocity from 50 km per hour due East. Two cars, starting from any given point and travelling, one with the first velocity and one with the second, would finish up in two quite different places at the end of any period of time.

A force is represented by a line with an arrowhead, as shown in Fig. 8.2.

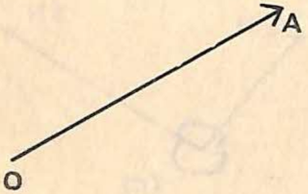


Fig. 8.2 **Graphical representation of a force**

The length of the line OA is proportional to the *magnitude* of the force. Thus a force of 10 newtons would be represented by a line twice as long as that which represented a force of 5 newtons.

The direction of the line in space corresponds to the *direction* of the force. Thus a vertical force would be represented by a vertical line and a horizontal force by a horizontal line. The arrowhead indicates the *sense* of the force i.e. a force acting vertically upwards would be represented by a vertical line with an arrow pointing upwards, while a force acting vertically downwards would be represented by a vertical line with an arrow pointing downwards.

The point O represents the *point of application* of the force i.e. the point on the body at which the force acts.

The force represented by the line OA in Fig. 8.2 is referred to as the force $\overrightarrow{OA}$. Note that $\overrightarrow{OA}$ is a vector as compared with OA which is a scalar.

In Fig. 8.1 (a) the resultant force, known simply as the 'resultant', is clearly 1 newton in the direction of the 3 newton force. In Fig. 8.1 (b) the resultant is 5 newtons in the direction of both forces. But what is the resultant in the case of Fig. 8.1 (c) and the case of Fig. 8.1 (d)? The following law, known as the law of the *Parallelogram of Forces*, tells us how to find out.

'If two forces acting at a point are represented in magnitude and direction by two adjacent sides of a parallelogram meeting at the point O, their resultant will be represented in magnitude and direction by the diagonal of the parallelogram through O'. (see Fig. 8.3.)

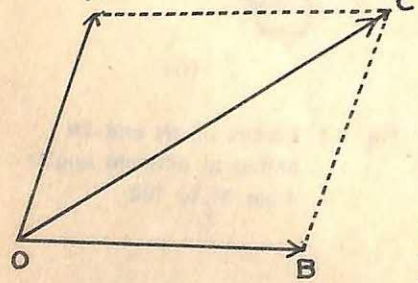


Fig. 8.3 **Law of the Parallelogram of forces**

Thus the resultant of forces $\overrightarrow{OA}$ and $\overrightarrow{OB}$ is the force $\overrightarrow{OC}$, and this fact can be expressed mathematically as

$$\overrightarrow{OA} + \overrightarrow{OB} = \overrightarrow{OC}.$$

So to find the resultant of forces 3 newtons and 2 newtons acting at any angle, 90° for example, we shall draw two lines to represent the forces 3 newtons and 2 newtons, and we shall draw them at an angle of 90°. Since the length of the representing line must be proportional to the magnitude of the force represented, these lines could be 3 cm and 2 cm respectively, or 6 cm and 4 cm respectively or 30 cm and 20 cm respectively, or in fact any lengths which are in the ratio 3 : 2. In Fig. 8.4 they are represented by

6 cm and 4 cm, and the diagonal OC tells us the resultant force, which, since it is a vector, must be stated in terms of both its magnitude and its direction. In this case, the resultant, since it is represented by a line 7.2 cm long, is a force of magnitude 3.6 newtons acting in a direction making an angle of 56° with the 2 newton force.

Making the necessary parallelogram construction in each case, find the resultant of forces of 3 newtons and 2 newtons acting at an angle of (a) 120°, (b) 60°. Your answers should work out to be: (a) the resultant is a force of 2.65 newtons acting at an angle of 79° to the 2 newton force, (b) the resultant is a force of 4.35 newtons acting at an angle of $36\frac{1}{2}$° to the 2 newton force.

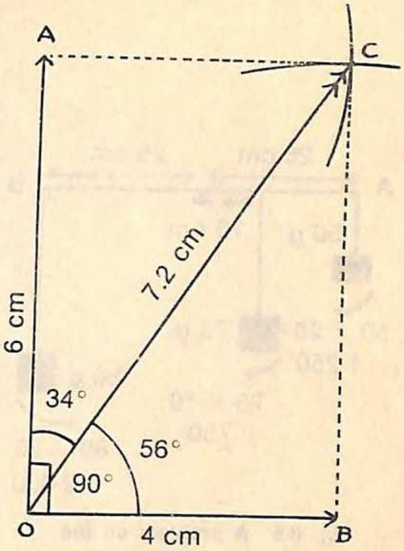


Fig. 8.4 **Parallelogram of forces for 3N and 2N acting at 90°**

2. More about Turning Forces

Look at the apparatus shown in Fig. 8.5 and explain how you would use it to verify the *Principle of Moments* which states that 'if a body is at rest under the action of a number of forces all acting in the same plane, then the sum of the clockwise moments of these forces about any point in their plane must be equal to the sum of the anticlockwise moments of these forces about the same point'. (The word 'torque' is also sometimes used for 'moment'.)

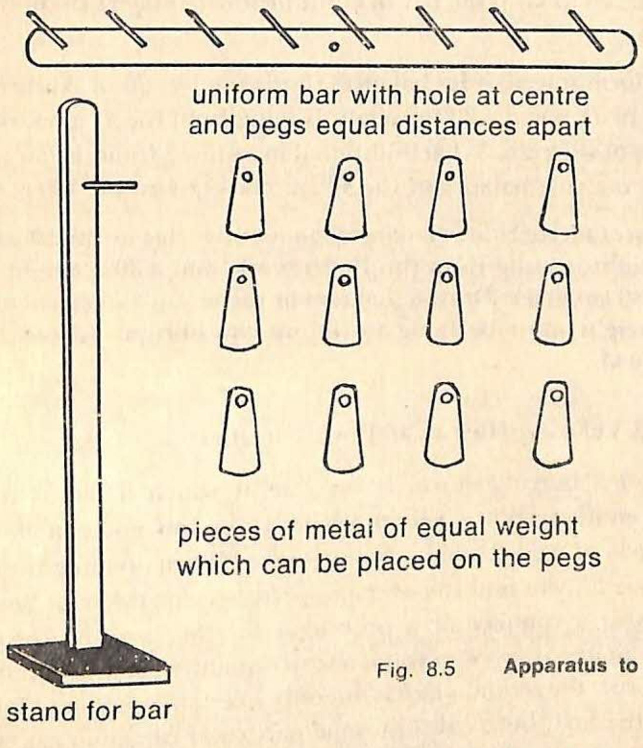

uniform bar with hole at centre and pegs equal distances apart
pieces of metal of equal weight which can be placed on the pegs
stand for bar

Fig. 8.5 **Apparatus to verify the principle of moments**

When a body is at rest under the action of a number of forces, it is said to be in *equilibrium*. The word is derived from 'aequus' which means 'equal' and 'libra' which means 'balance'. Two equal pans of a balance, loaded with equal weights, would balance each other, so that the rod or beam connecting them would be at rest, or in equilibrium.

Here is a simple problem on the principle stated above. Its solution is also given. (see Fig. 8.6.) Remember that a uniform bar is one of the same material and thickness all over, and so its weight will act at the middle point.

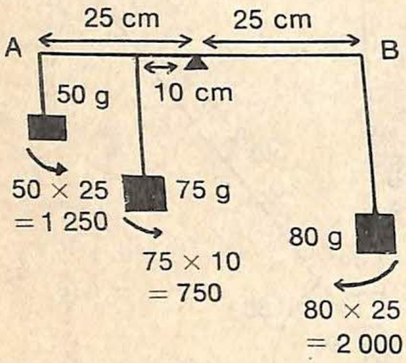


Fig. 8.6 **A problem on the principle of moments with its solution**

Problem. A uniform bar AB 50 cm long is pivoted at its middle point. A weight of 50 g is attached to end A, and a weight of 80 g is attached to the other end B. What weight must be attached 15 cm from end A to produce equilibrium?

Solution. The 50 g weight at A exerts an anticlockwise moment of 1 250 units. The 80 g weight at B exerts a clockwise moment of 2 000 units. So there is an extra clockwise turning effect, or moment, of $2000 - 1250 = 750$ units, which must be balanced by an anticlockwise moment of 750 units. Since the force is to act at a distance of 10 cm from the pivot, its magnitude must be $\frac{750}{10} = 75$ g.

Now try these three problems:

1. A uniform bar 60 cm long is suspended by a string tied to its centre. Loads of 100 g and 200 g are attached at points 12 cm and 24 cm from one end. Draw a diagram of the set up, and calculate where a load of 200 g must be placed to keep the bar in equilibrium. (*Answer:* 15 cm from the other end).

2. A uniform metre-rule balances horizontally on a knife-edge at the 20 cm mark when a 200 g weight is hung from the 5 cm mark. What is the mass of the rule? What additional mass hung from the 60 cm mark will make the rule balance at the 50 cm mark? (*Answer:* 100 g; 900 g).

3. A uniform metre rule is balanced on a knife-edge at the 50 cm mark. A 50 g weight is hung from the 10 cm mark, and a 20 g weight is hung from the 80 cm mark. Draw a diagram of the set up and calculate where a 100 g weight must be hung to restore equilibrium. (*Answer:* at the 64 cm mark).

3. Speed and Velocity: How to add two velocities

The *speed* of a moving object is the rate at which it moves from one position to another. When you travel by train you find out how much distance is to be travelled and how long it takes. Then dividing the distance 's' by the time 't', you find the average speed 's/t' for the trip. You do not need a map or a compass or a protractor for this, because the distance between the places as given to you is a scalar quantity, and does not involve direction. True, the second place is not only a certain number of kilometres away from the first, but is also in some particular direction e.g. north, or north-east, or south from it, but this information is not necessary for calculating the speed, as *speed is a scalar* and does not involve direction. The indicators on the instrument panel of a car tell us the distance covered in kilometres, and the speed at which the car is moving in kilometres per hour without any reference to direction. When we say that the maximum speed a particular car is capable of is 150 kilometres per hour this refers to its maximum rate of moving, and can be in any direction.

Distance travelled in a given direction is called 'displacement'. Displacement is a vector, so any two displacements will be added by the parallelogram law stated earlier. Thus if I move 6 kilometres due north and then 4 kilometres due east, I have suffered two displacements and the total effect of these, i.e. the total displacement I have suffered, could be calculated from a scale drawing of the parallelogram concerned and will be seen to be 7.2 kilometres in a direction 34° east of north. Look at Fig. 8.4 and consider how this would be the scale drawing needed.

The rate of displacement of a body is its velocity, and so *velocity is a vector; it is speed in a given direction*. If, as in Fig. 8.4, I suffer a displacement of 7.2 kilometres in a direction 34° east of north in 8 seconds, my speed is $7.2/8 = 0.9$ kilometres per second, but my velocity is 0.9 kilometres per second in a direction 34° east of north.

Velocities being vectors must be added by the parallelogram law. Thus Fig. 8.4 gives the answer to the question 'What is the resultant of two velocities of 60 km per hour and 40 km per hour at right angles to each other?' The answer would be 'a velocity of 72 km per hour in a direction at 34° to the 60 km per hour velocity and at 56° to the 40 km per hour velocity'. Suggest another pair of velocities that could be added together by the scale drawing shown in Fig. 8.4.

Suppose an airplane flies through still air with a velocity of 300 km/hr eastward. Suddenly a tail wind with a velocity of 25 km/hr eastward springs up. What is the resultant velocity of the airplane? Since the wind's velocity is in exactly the same direction as that of the airplane it will cause a resultant velocity of 325 km/hr eastward. Now let us consider the opposite case. The airplane flies eastward, but the wind is a head wind. Its velocity is 25 km/hr westward. What is the resultant velocity of the airplane? 300 km/hr eastward + 25 km/hr westward = 275 km/hr eastward. In a third case, the airplane still flies eastward with a velocity of 300 km/hr, and the wind has a velocity of 25 km/hr southward. Fig. 8.7 is a scale drawing representing this situation. The scale used is 1 cm represents 20 km/hr. Very careful construction and measurement would show that the resultant velocity of the airplane is 301 km/hr in a direction 4.8° south of east. This direction is referred to as 094.8°, due east being 090°, and due south being 180°. This system of stating direction starts from due north and measures the angle of the required direction in degrees towards the east. Thus due west would be 270°, towards north-west would be 315°,

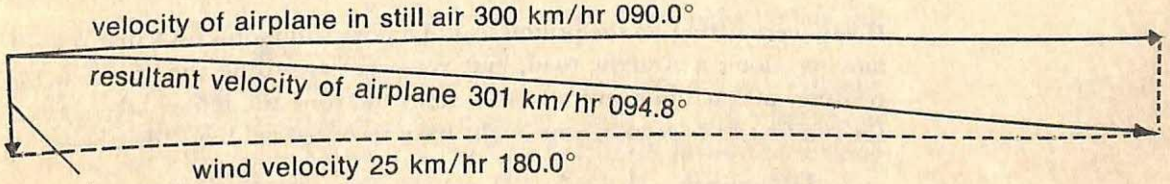

velocity of airplane in still air 300 km/hr 090.0°
resultant velocity of airplane 301 km/hr 094.8°
wind velocity 25 km/hr 180.0°

Fig. 8.7 **Parallelogram of velocities for 300 km/hr East and 25 km/hr South**

towards north-east would be 045°, etc. The direction so stated is known as the *true bearing*.

The pilot of the airplane, however, does not want to get 25 miles south of his course for each hour of flight. What change must he make in the velocity of his airplane so that he stays on course despite the wind blowing from the north? Now the resultant velocity we wish to obtain is 300 km/hr 090°. This is represented by OR in Fig. 8.8. It is the diagonal of the parallelogram of velocities. We know one side of this parallelogram, that which represents the wind's velocity, 25 km/hr 180°, represented by OS To complete the parallelogram, we first draw SR. Then from O, OV is drawn parallel and equal to SR. Connecting V to R completes the parallelogram. OV represents the velocity the airplane must maintain, and careful construction and measurement would show that it would be 301 km/hr with a bearing of 085.2°. By heading his airplane on a bearing of 085.2° and increasing his airspeed to 301 km/hr, the pilot actually travels with a velocity of 300 km/hr 090°.

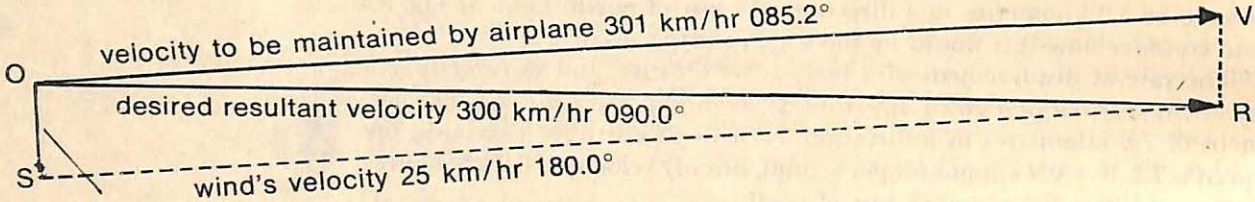

O
V
R
S
velocity to be maintained by airplane 301 km/hr 085.2°
desired resultant velocity 300 km/hr 090.0°
wind's velocity 25 km/hr 180.0°

Fig. 8.8 **Making good a track of 090° with a ground-speed of 300 km/hr in a north wind of 25 km/hr**

A ship sailing in water which is moving with a velocity, has a similar problem in directing its course so that it moves along its desired track despite the drift caused by the current. Both ships and airplanes carry navigators who work out their course by the method explained above.

4. Acceleration

If you were sitting on the pillion seat of a powerful motor bike that started moving along a straight road, and you were recording the speedometer reading, in km/hour, every second from the time the motor bike started for the first few seconds, you might have recorded readings like these:

Time	0	1	2	3	4	5	6	in seconds
Speed	0	18	36	54	72	90	108	in km/hour

In practice the speed of a motor cycle or car does not usually increase in this uniform way. The power of the engine is not constant at all speeds, frictional and air resistances vary, and changing gears also prevents such uniform increase in velocity. However, let us assume for the purpose of discussion that the velocity did change as shown above. We see that the velocity changes at the uniform rate of 18 km/hr every second. *The rate of change of velocity of a moving body is called its acceleration.* Thus the acceleration of the motor cycle is, in this case, uniform and it is 18 km/hour every second in the direction of the straight road. Now 18 km per hour $= \frac{18 \times 1\,000}{60 \times 60}$ m per sec = 5 m per sec, so we see that the acceleration of the motor cycle is 5 m per sec per sec, which is generally written as 5 m/sec^2 or 5 m/s^2, in the direction of the straight road.

Similarly if a moving body had a velocity of 10 m/s at a certain instant, and a velocity of 60 m/s five seconds later, then in 5 seconds its velocity changed by (60 − 10) = 50 m/s so in every 1 second its velocity changed by $\frac{50}{5} = 10$ m/s. Thus the acceleration is 10 m per sec per sec or 10 m/s^2.

From this we see that

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{time in which the change took place}}$$

It must be noted that since the acceleration of a body is its rate of change of velocity and its velocity is its rate of displacement, the matter of rate, and therefore of time, will enter twice into the unit of acceleration which is, as we have seen, m/s^2. We must also note that since velocity is a vector, acceleration which is a change in velocity divided by time is therefore a vector quantity divided by a scalar quantity, and so *acceleration is* also *a vector* quantity.

It must also be noted that although the acceleration described above was uniform, accelerations are quite often not uniform. Cars accelerate more on clear and open roads, and slow down in heavy traffic. Trains move faster when they have a long clear run, but slow down and stop near stations or at points where they are signalled to stop.

One case of uniform acceleration is of particular importance in Physics. It is the acceleration due to gravity. The earth as we know attracts bodies to itself and causes them to fall to its surface. This tendency to fall is opposed by the resistance and the buoyancy of the air. This leads to the observation that different objects fall to the earth at different speeds, and causes some confusion of thought. Stones, iron balls and pieces of lead fall faster than feathers, leaves and snowflakes, so it would seem that heavy bodies fall faster than light ones. But on the other hand, a pebble falls as fast as a large heavy stone, which seems to suggest that light bodies will fall as fast as heavy ones. What is the truth?

About 2 400 years ago Aristotle (384–322 B.C.), a Greek scholar, attempted to find the answer. But instead of dropping a light ball and a heavy one together and observing their motion, or in other words instead of making an experiment, Aristotle reasoned that the speed of a falling body was directly proportional to its weight, and that therefore a 2 kg ball falls twice as fast as a 1 kg ball.

At that time few people, if any, were interested enough to question Aristotle's conclusion and as his reputation as a scholar grew over the years, succeeding generations did not dare to question his word on any subject.

Galileo Galilei (1564–1642), a young professor at the University of Pisa in Italy, was the first to really test Aristotle's conclusion. By experiment he found that a musket ball would fall as fast as a cannon ball. But when Galileo announced his discovery to his learned associates, most of

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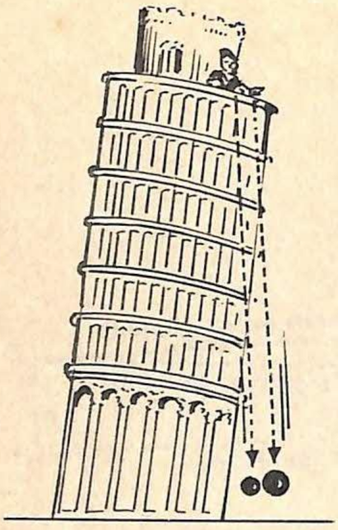


Fig. 8.9 **Galileo at the Leaning Tower of Pisa**

whom were followers of Aristotle, they refused to listen, and ridiculed Galileo for daring to challenge the teachings of the great Aristotle. Determined to prove them wrong, one morning before the assembled students and professors, Galileo climbed to the top of the now famous Leaning Tower of Pisa and simultaneously dropped a small musket ball and a large cannon ball. They fell together and they hit the ground together. The tower was ideally suited to the experiment, because it leaned enough (see Fig. 8.9) so that the falling balls would not strike its sides, and it was tall enough (55.8 m high) so that the results of the test would be convincing. Because of this epochal experiment, Galileo has been called the *father of experimental science.*

Galileo's experiment proved that a heavy cannon ball does not fall faster than a light musket ball, but it did not explain why a stone falls faster than a feather. Galileo explained that the difference in speed is due to air resistance; air offers more resistance to a falling feather, in proportion to its weight, than to a stone. This hypothesis, an unproved explanation of facts, could be proved or disproved only by the dropping of a stone and a feather together in a vacuum. With the invention of the air or exhaust

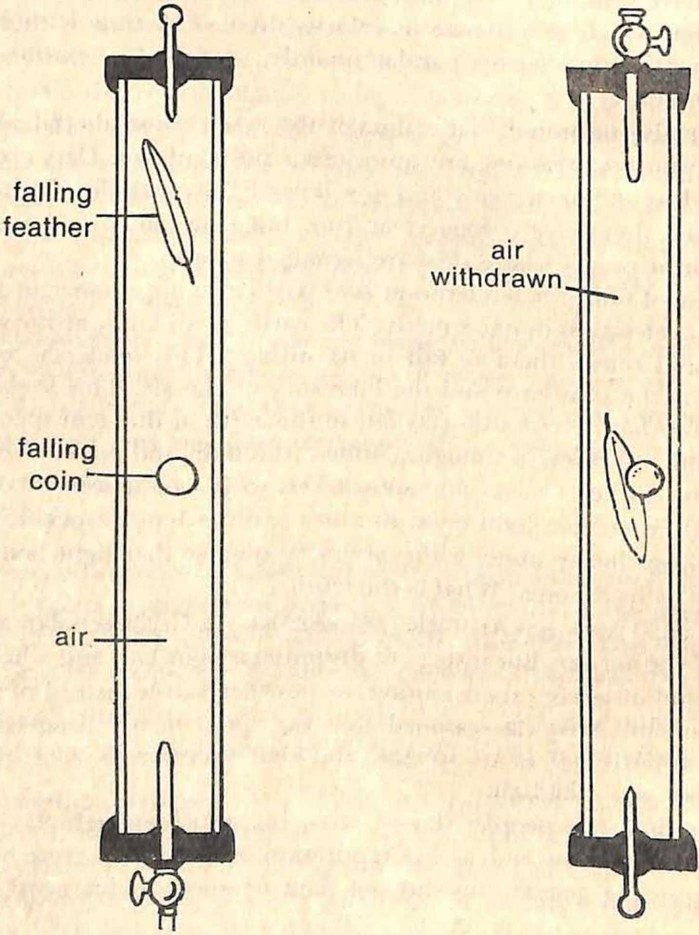


Fig. 8.10 **The 'Coin and feather' experiment**

pump, it became possible to test this hypothesis. The apparatus used is shown in Fig. 8.10. Inside the tube are a feather and a coin. If the air is drawn out of the tube with an air pump and the tube is inverted, the coin and the feather will be observed to fall together. If the air is re-admitted, and the tube again inverted, the feather will flutter down slowly, while the coin falls much more rapidly.

From what has been said it should now be clear that the acceleration due to gravity, denoted briefly in Physics by 'g', is the same for all bodies. The value of this acceleration varies slightly at different points on the earth's surface, being greater at those points which are closer to the centre of the earth. On the earth's surface near the equator $g = 9.78\ m/s^2$. At the North and South Poles it is $9.83\ m/s^2$, in London it is $9.81\ m/s^2$, and at the author's school laboratory in Darjeeling it is $9.785\ m/s^2$. The value of 'g', for general numerical calculation, is usually rounded off to $9.8\ m/s^2$. This means that when an object falls under gravity its velocity, due to the pull of gravity, increases by 9.8 m/s every second, and when it rises against the pull of gravity, as for example when it is thrown up, its velocity decreases by 9.8 m/s every second, as shown in Fig. 8.11.

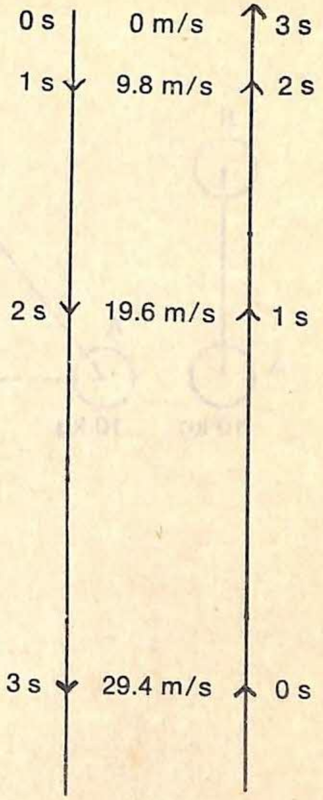


Fig. 8.11 **Upward and downward motion under gravity**

5. Work and energy

In Chapter 5 of this book we learnt that when a force moves a body it does 'work' on the body, and that the work done by the force on the body is calculated by multiplying the magnitude of the force by the distance moved by the body. Now it may happen that the body may not move in exactly the same direction as the force. In such a case we must be careful, when calculating the work done by the force on the body, to multiply the magnitude of the force by the distance moved by the body *in the direction of the force.* Thus in Fig. 8.12(i) the work done by the force on the body is F × AB, but in Fig. 8.12(ii) it is not F × AB but F × AC; although AB is the actual distance moved by the body, AC is its displacement in the direction of the applied force.

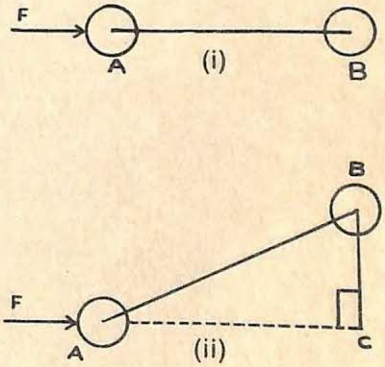


Fig. 8.12 **(I) and (II)**

Work = Force X Distance

The force applied will usually be measured in 'newtons', and the distance moved by the body in 'metres'. The work done will therefore be in 'newtons × metres' which are called 'joules'. Thus if a force of 6 newtons moves a body through 5 metres in its own direction, it has done $6 \times 5 = 30$ joules of work on the body. We have learned that to lift a body weighing 1 kg we have to exert an upward force of 9.8 newtons, so if I lift a 1 kg weight through a vertical distance of 50 cm, I will have done $9.8 \times \frac{1}{2} = 4.9$ joules of work on it. If the body weighed 10 kg I would have to exert an upward force $10 \times 9.8 = 98$ newtons to lift it, and if I raised it vertically through 5 metres the work done would be $98 \times 5 = 490$ joules. Note that in Fig. 8.13, in which a 10 kg weight is being raised from A to B the work done is the same, 490 joules, in each case, because the vertical height through which the body is raised is the same in each case. When a body is lifted, its weight, which is a vertical force, is opposed and the vertical distance through which it is raised must be considered in calculating the work done in lifting it.

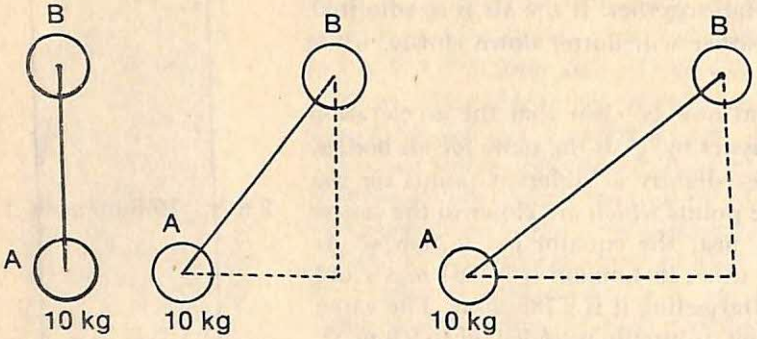


Fig. 8.13 *A 10 kg weight is raised from A to B at different angles. The work done is the same in each case because the force applied is the same, and the vertical distance moved is the same.*

'Energy' is required to do work, and energy is measured in the same unit as work i.e. in joules. Thus 50 joules of energy must be expended in doing 50 joules of work. But energy need not only do the type of work described above. Energy has a broader meaning. It is not only, as we saw in Chapter 2, a capacity for doing work, but it is also a capacity for bringing about any physical effect or result. In Chapter 2 we studied many different types of energy. We learned about potential energy and kinetic energy, about heat energy, light energy, sound energy, magnetic energy and electrical energy. We learned something of the effects each of these different types of energy could produce, and we also learned that energy is capable of transformation from one form to another form, or to more than one other form, and that during every such transformation energy is never lost. When I lift a mass of 10 kg vertically through 5 metres, I do 490 joules of work. To do this work I must use 490 joules of energy, originally stored as potential energy in my muscles. Can you suggest how this energy came there? When I spend this energy in lifting the body, the energy I spend is not lost but is stored up in the body as potential energy. In falling back to its original position the body can give up this 490 joules of potential energy in doing 490 joules of work. Suppose the body fell from the height it was raised to on to a peg and drove it 5 cm into the ground. What would the resistance of the ground be? 9800 newtons? or 9898 newtons? Remember that the ground must not only do work against the body and bring it to rest, but must also support the weight of the body (98 newtons) during the process. The above calculation however presupposes that the energy of the body viz. 490 joules is entirely utilised in driving the peg into the ground. Normally a thud would be heard indicating some production of sound energy, and there would be heat generated by the impact. Now if sound and heat were so generated and if the resistance of the ground remained 9898 newtons, would the peg penetrate 5 cm into the ground? If not would it penetrate more, or less?

When you walk up a flight of stairs you do work against gravity i.e. against your own weight. The higher you climb the more work you do and the more energy you spend, and the more tired you feel. When you walk a considerable distance on a level ground, you do not do any work against gravity because you do not rise vertically through any distance. But you do feel tired, which indicates that you have spent energy. This means that you have done work. What force have you overcome? A ball which has been kicked rolls further on a smooth cement floor than on a gravel path. Explain why, and trace all the energy changes that occur from the act of kicking till the ball stops.

We learned in Chapter 2 of a unit of heat energy called the 'calorie'. One calorie is the amount of heat required to raise the temperature of one gram of water by one degree Centigrade. Thus to raise the temperature of 100 g of water by 20 degrees Centigrade would require 100 × 20 = 2 000 calories. This heat energy could be provided by an electric heater i.e. by an electric current. Assuming that all the electrical energy developed in the heater is converted to heat energy in the water, then from the principle of conservation of energy, this would mean that the electrical energy produced by the heater was 2 000 calories. But electrical energy is not measured in calories, which are only used for measuring heat energy. Electrical energy is measured in joules, and this raises the question how many joules are equal to 2 000 calories, or for that matter how many joules are equal to 1 calorie. An English physicist, James Prescott Joule, made experiments and established the fact that 4.2 joules are equivalent to 1 calorie. The unit 'joule' has been named after him. This also raised the question that if there is no separate unit for electrical energy why should there be a separate unit, the calorie, for heat energy. Energy is a unifying principle in Physics, and it is therefore advisable that we have one common unit to measure all forms of energy. This unit is the joule. It is becoming increasingly common to measure heat energy also in joules, and to refer to the heat required to raise 1 g of water by 1°C as 4.2 joules and not as 1 calorie. To give you some idea of how much energy 1 joule represents, the work done in lifting an apple from the floor on to a table is about 1 joule. In a hard day's work a man might expend about 1 million joules.

It would be most helpful at this stage to read over Chapter 2 again, bearing in mind that in all cases of transformation of energy, there is neither loss nor gain of energy. The energy may sometimes be transformed from forms that are useful to forms that are useless, e.g. sound and heat may be produced, but energy is never lost. In cases where it is transformed from useful forms to forms that are not useful we say that the energy has been *dissipated*.

6. Machines

A simple machine is a device that enables us to do work more easily than would be possible without it. Every time we use a knife or a fork, lift earth or sand with a shovel, turn a screwdriver, climb a staircase, turn a door knob, or steer a car, we are using a simple machine.

Some simple machines make it possible to multiply force. Suppose it was necessary to change a flat tire on a motor car. A man cannot exert enough force to lift the car so that the tyre can be changed. With a car jack, the force which he exerts on the jack results in a force many times greater being applied to the car. For this reason the jack is said to multiply the force that the man exerts upon it. Bottle openers, scissors, pump handles, can openers, nut crackers, pliers, and wrenches are all simple machines that multiply force.

Some simple machines are used to change the direction of a force. For example, the pedal of a bicycle is arranged so that the rider can push downward with his legs and the force he exerts will pull him forward. The single pulley at the top of a flagpole enables a downward force to raise a flag upward to a great height. Changing the direction of a force is often the only reason for using a simple machine.

Some simple machines make it possible to gain speed and distance. When you sweep with a broom, your hands should move slower and through a shorter distance than the bristles of the broom do. When you lift earth on a shovel, the earth should travel faster and through a greater distance than your hands do. Fishing rods, hockey sticks, and cricket bats also make a gain of speed and distance possible.

We shall now study a few simple machines.

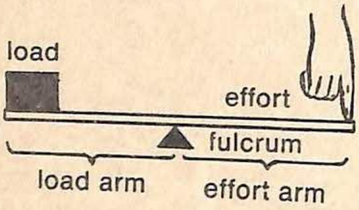


Fig. 8.14 **Terminology of the lever**

The lever. A scientist in ancient times is said to have claimed 'Give me a lever long enough and a place upon which to support it, and I could lift the world!' Of course such a feat would be impossible, but without the use of levers, our modern civilization could not exist.

We all use levers every day. Our fingers, arms, and legs are levers. By using them we can move about, pick up objects, and apply force in many ways. Knives, forks, shovels, brooms, and scissors are other levers that we frequently use. A study of levers will help us understand how we can use them more effectively. In Fig. 8.14 note that the point about which the lever turns is called the *fulcrum*. At one end of the lever is the *load* or resistance to be overcome, while at the other end of the lever a force called the *effort* is applied. The part of the bar, serving as the lever, between the effort and the fulcrum is called the *effort arm*, and the part between the fulcrum and the load is called the *load arm*. From the principle of moments we see that

$$\text{Load} \times \text{load arm} = \text{Effort} \times \text{effort arm}$$

$$\text{or,}\quad \frac{\text{Load}}{\text{Effort}} = \frac{\text{effort arm}}{\text{load arm}}$$

This means that the force applied will be multiplied by as many times as the effort arm is greater than the load arm. Thus in Fig. 8.15 a force

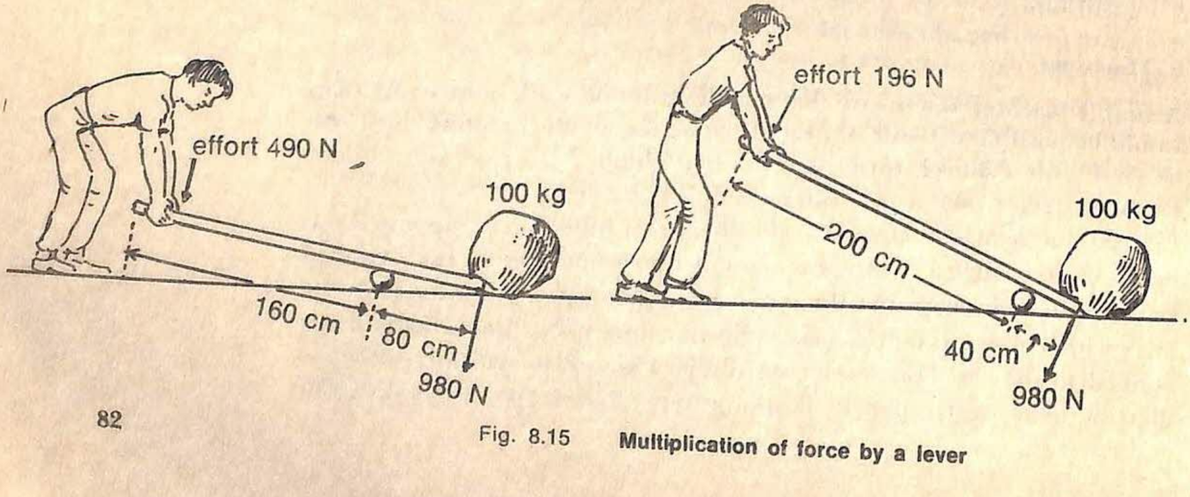


Fig. 8.15 **Multiplication of force by a lever**

equal to the weight of 50 kg i.e. a force of 490 N (N being the symbol for newton) will be needed to raise the 100 kg load when the effort arm is only twice as long as the load arm, but a force equal to the weight of 20 kg i.e. a force of 196 N is enough when the effort arm is five times as long as the load arm.

In Chapter 5, Fig. 5.7, diagrams of many levers are shown. Study each lever, and, noting the positions of the fulcrum, load and effort in each case, try and estimate how long the effort arm and the load arm are in each case, and from these estimated values work out by how much the effort force is multiplied to produce the force acting on the load, or in other words how many times greater the force got out is than the force put in. For example take a pair of scissors, measure the effort arm and the load arm with a ruler, and from these values calculate how much force is exerted on the material being cut when you apply an effort force of 1 N to the scissors.

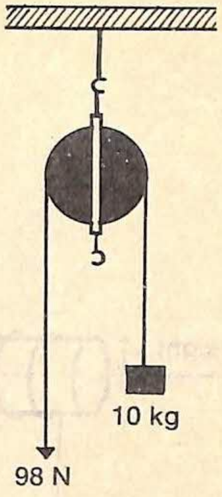
The pulley. Fig. 8.16(i) shows a single fixed pulley. This does not multiply the applied force, or effort, into a greater force to lift the load. It merely changes the direction of the applied force. By pulling down on a rope we can hoist a flag up to the top of a high flag pole. Here the use of the machine lies in its convenience; it is easier to lift the load up to a great height by pulling down, even though we must exert as strong a force as the weight of the load.

Fig. 8.16(ii) shows a single movable pulley. This does not change the direction of the applied force – an upward force is required to move a load upward, but it multiplies the effort by two or in other words an effort equal to half the weight of the load is required.

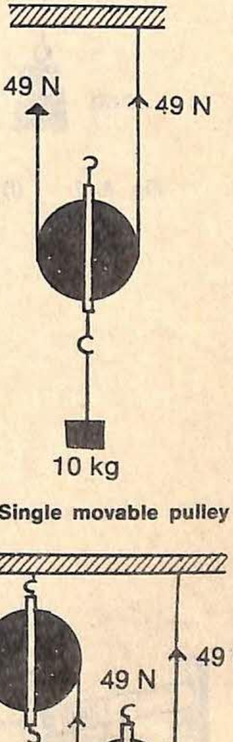
Fig. 8.16(iii) shows a combination of the two. Such a combination provides the advantages of both the pulleys described above i.e. this system enables the lifting of a load by a force equal to only half the weight of the load, and enables the lifting to be done by a downward force which is more convenient.

More elaborate pulley systems, which produce forces four times and six times as great as the applied force, and with the convenience of a downward direction for the effort as well, are shown in Fig. 5.12. Such a pulley system, known as a 'block and tackle', makes it possible to lift very heavy loads with much smaller efforts. Draw a diagram of a block and tackle system with four pulleys in each block, the rope starting from the upper block and the effort being downward. Calculate the number of strands of rope that support the load, and work out how much effort is required to lift a load of 8 kg. Remember that whatever effort is applied will operate throughout the entire length of the rope, i.e. along each strand, and that the entire load is shared by all the strands so that each strand bears only a proportionate fraction of the load.

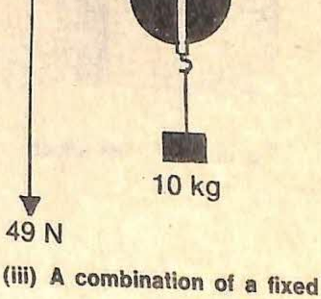
The wheel and axle. The wheel and axle consist of a wheel mounted on an axle of smaller radius. Ropes are coiled around each in opposite directions as shown in Fig. 8.17(i). The effort, applied at the end of the rope coiled around the wheel, can lift a much heavier load at the end of the rope coiled around the axle.



(i) Single fixed pulley



(ii) Single movable pulley



(iii) A combination of a fixed and a movable pulley

Fig. 8.16

To understand the multiplication of force developed by this machine, imagine that you were looking at the apparatus along the line of sight indicated by the arrow. What you would see is shown in Fig. 8.17(ii). The load and the effort exert opposite moments. The clockwise moment = effort × R and the anticlockwise moment = load × r. If they balance each other, then applying the principle of moments we have

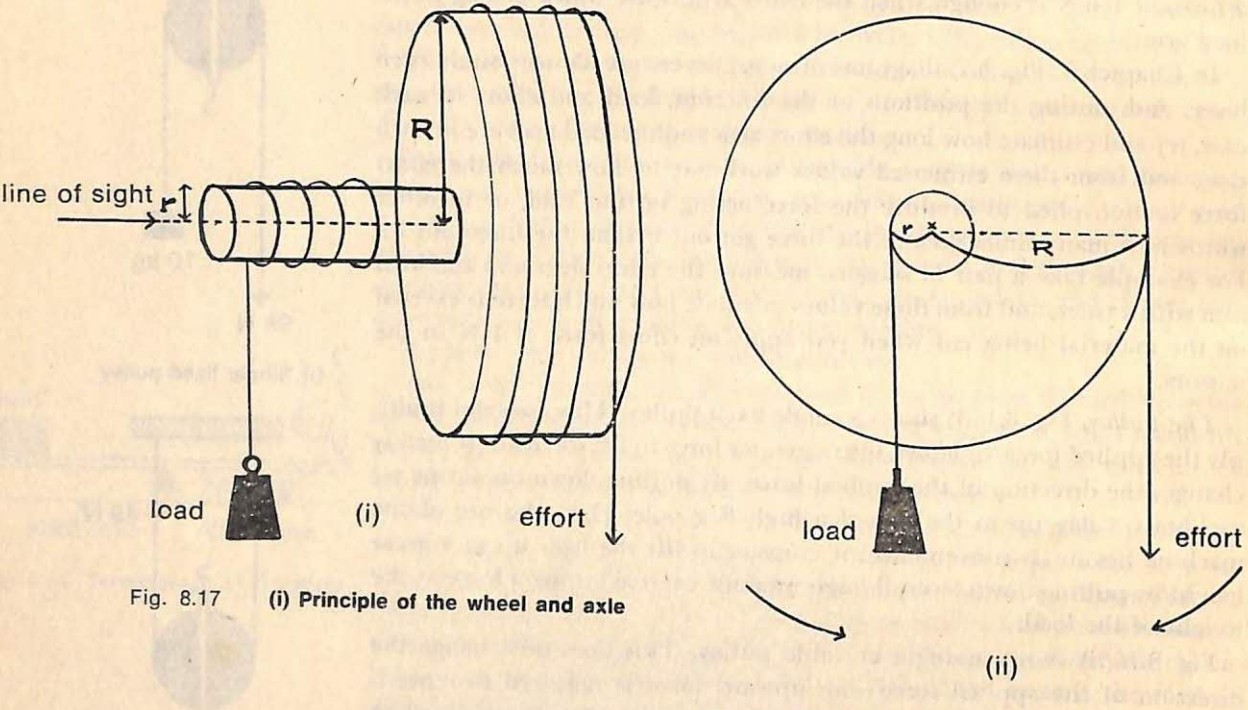


Fig. 8.17 (i) **Principle of the wheel and axle**

(ii) The wheel and axle works on the lever principle

$$\text{load} \times r = \text{effort} \times R$$

$$\text{or,} \quad \frac{\text{load}}{\text{effort}} = \frac{R}{r} = \frac{\text{radius of wheel}}{\text{radius of axle}}$$

Thus if the radius of the wheel is 12 times the radius of the axle, the force got out will be 12 times the force put in, or in other words we can lift a load with an effort equal to one-twelfth of its weight. A common form of the wheel and axle is the winch shown in Fig. 8.18.

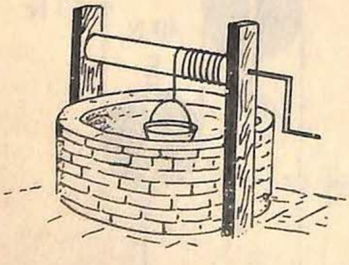


Fig. 8.18 **The winch**

Another example is the turning of the steering wheel of a motor car. The effort is applied to the rim of the steering wheel. The load is the resistance to be overcome in moving the front wheels of the car. The axle connected to the steering wheel moves the load and turns the front wheels. If the steering wheel came off it would require enormous strength to steer the car by grasping this axle.

Look at Fig. 8.17(ii) and compare it with Fig. 8.14. You will soon realise that the wheel and axle is another application of the lever principle. The radius of the wheel is the effort arm, and the radius of the axle is the load arm.

The inclined plane. When men load and unload heavy objects from a truck they often use another simple machine. It is merely a long plank or platform extending from the bottom of the truck to the ground, up or down which the load travels.

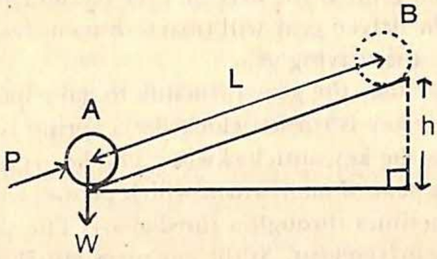


Fig. 8.19 **The inclined plane**

To understand the multiplication of force in this machine, study Fig. 8.19. To move the object from A to B requires work to be done. The effort, represented by force P, moves the body through a distance L, the length of the plane, in its own direction. Thus the work done, being force × distance, is equal to P × L. But this work is equivalent to the raising of the load, represented by the force W, through the vertical distance h, and so is also equal to W × h Therefore,

$$W \times h = P \times L$$

$$\text{or} \quad \frac{W}{P} = \frac{L}{h}$$

$$\text{in other words,} \quad \frac{\text{Load}}{\text{Effort}} = \frac{\text{length of plane}}{\text{vertical height of plane.}}$$

The system has been described as a means of 'diluting gravity'. Instead of a greater force moving a body through a shorter distance, a smaller force does the same work by moving the body through a greater distance. The greater force, the weight of the body, is diluted into a weaker force at the expense of moving it through a greater distance.

Inclined planes were among the first simple machines used by man, and are still used in a great variety of ways. A staircase, a road winding up a hill, and a ramp are all examples of an inclined plane.

It is thought that a huge inclined plane was used during the construction of the Great Pyramid near Cairo. Over two million limestone blocks were used to build the Pyramid each having a mass of more than 2 000 kg. 100 000 slaves are estimated to have worked for 20 years to build it.

The Gear. A gear is a wheel with teeth around its rim. Two gear wheels with properly cut teeth can be fitted together so that as one is turned it will turn the other, but in the opposite direction, as shown in Fig. 8.20. If the first wheel has 10 teeth, or cogs as they are also called, and the second wheel has 20 teeth engaging, or meshing, with the teeth of the first wheel, then as the shaft A turns the first wheel clockwise, the second wheel is turned anticlockwise at half the speed but with twice the turning effect, or moment, or 'torque' as it is also called. In other words speed is sacrificed

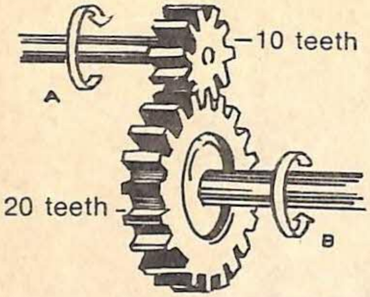


Fig. 8.20 **Geared wheels**

for increase in turning effect or torque. In this case A is the driving gear and B the driven gear. Note that the operation can be reversed i.e. B can be turned causing A to turn faster but with less torque, or in other words torque is sacrificed for increase in speed when the driving gear has more teeth than the driven gear. If the driving gear has 60 teeth and the driven gear has 10 teeth, the driven gear will turn 6 times as fast as, but with one-sixth the torque of, the driving gear.

The toy motor car uses the gear principle to gain speed at the expense of torque. When the key is turned clockwise a spring is wound up which when released turns the key anticlockwise. The key is on an axle or shaft fitted with a driving gear of many turns which meshes with the driven gear of fewer turns (sometimes through a third gear). The wheels are fitted to the same axle as the driven gear. As the key turns anticlockwise at a certain speed, depending on the strength of the spring, the wheels turn clockwise at greater speed.

Open the back of a toy motor car. Count the number of teeth on the driving gear and the number of teeth on the driyen gear. Divide the first number by the second number and note the answer. Turn the key anticlockwise and count the number of times the wheels turn for one turn of the key. Compare the first number you noted with this number. Now while turning the key place your finger against a wheel and try and compare the torque or turning strength of the key with that of the wheel. Which is greater? In this case we have a slow-moving engine and a fast-moving car.

The reverse process i.e. gaining torque at the expense of speed is employed in the engine of a car when it is ascending a hill. It requires more torque to go up a hill than to drive along a level road, and so the driver changes gears, and engages or meshes a driving gear of fewer teeth with a driven gear of many more teeth. The higher the ratio of teeth on the driven gear to teeth on the driving gear, the greater the torque developed. In this case we have a fast-moving engine and a slow-moving car.

In conclusion we must note that while some machines are direction changers, and others are force-multipliers and others are speed-multipliers, none of them are energy-multipliers. This follows from the law of conservation of energy which we studied in the last section.

Questions

1 Explain the difference between vector and scalar quantities. Give four examples of each.

2 What is meant by the 'magnitude', 'direction', 'sense', 'line of action' and 'point of application' of a force? How is a force represented graphically? Explain how this form of representation includes all the aspects of a force enumerated earlier in this question.

3 Explain why vectors cannot be added by the same laws of arithmetic by which scalars are added. Explain how two inclined vectors are added.

4 a Find the resultant of two forces, of magnitude 75 N each, exerted on an object if the angle between them is 60°.

b What would be the effect on the magnitude of the resultant of increasing the angle between the forces?

c How could these forces be made to yield a larger resultant?

5 Three forces acting at a point are in equilibrium. Two of these forces are 20 N and 30 N respectively, acting at right angles to each other. Find the direction and magnitude of the third force.

6 Calculate the moments about the pivot of the following forces: (give the answers in 'newton metres'.)

a A force of 10 N, if its line of action is at a perpendicular distance of 40 cm from the pivot.

b A force of 0.5 N, if its line of action is at a perpendicular distance of 8 m from the pivot.

c A force of 60 N, if its line of action is at a perpendicular distance of 2 m from the pivot.

7 Find the magnitudes of the following forces:

a A force which gives a moment of 600 newton metres about a pivot at a perpendicular distance of 8 m from its line of action.

b A force which gives a moment of 560 newton metres about a pivot at a perpendicular distance of 70 m from its line of action.

8 Find the perpendicular distance from the pivot to the line of action of the following forces:

a A force of 14 N which gives a moment of 420 newton metres about the pivot.

b A force of 27 N which gives a moment of 108 newton metres about the pivot.

9 A minimum force of 70 N is needed to open a stiff tap when a handle 30 cm long is used to turn the tap. What would be the minimum force needed if the longest handle available were only 10 cm long?

10 A rod whose weight may be neglected, and which does not bend, is balanced across a knife-edge. The rod remains in equilibrium when a 1.0 kg weight hangs from a point 60 cm from the knife-edge, and a stone of unknown weight hangs from a point 40 cm from the knife-edge. Find the moment produced by the 1 kg weight, and thence write down the moment produced by the stone. Calculate the weight of the stone. Does the knife-edge exert any force on the rod? If so, how great a force and in what direction?

11 You are provided with a metre stick, a piece of string, a 50 gram weight and a knife-edge. Explain, with a diagram, how you would use these to find the weight of the metre stick.

12 A rod 120 cm long is pivoted at one end and hangs vertically. A

piece of string is fastened to the rod at a distance of 25 cm from the pivot and is pulled horizontally to the right with a force of 10 N. Another piece of string, attached to the free end of the rod, is pulled horizontally and to the left with a force of 5 N. At what distance from the pivot, and in what direction, must a horizontal force of 7 N be applied to stop the rod turning?

13 Explain the difference between 'distance' and 'displacement', and between 'speed' and 'velocity'.

A stone, tied to a string, is whirled around in a circle so that it covers equal distances along the circle in equal intervals of time. Which of the following: (i) the displacement of the stone (ii) the speed of the stone (iii) the velocity of the stone, are constant? Give reasons.

Does the stone have an acceleration? If so is its acceleration constant? Give reasons.

14 A plane travels 80 km north. It then travels 64 km in a direction 60° east of north (i.e. on a 'true bearing' of 060°), and finally 120 km in a direction 70° south of west (i.e. in a direction 200° east of north viz. on a 'true bearing' of 200°). By drawing a scale diagram calculate its total displacement.

15 Using a scale of 1 cm to represent 40 km/hr, construct a vector diagram to find the resultant velocity for an aircraft that is travelling with a velocity of 480 km/hr due east, and is deflected off course by a north wind blowing at 160 km/hr.

16 If in the above problem the plane flew with the same speed of 480 km/hr in the same wind, calculate by drawing a vector diagram the course it would have to steer if it wished to move due east.

17 In an experiment, a body moved the following distances in successive intervals of one-fifth of a second each:

5.0, 8.2, 11.2, 14.4, 17.5, 20.7 metres.

Write down its velocity in the first one-fifth second, and its velocity in the last one-fifth second, and from these calculate its acceleration.

18 What is meant by the statement that '$g = 9.8\ m/s^2$'?

A body falls freely for 7 seconds. Using this value of 'g' calculate its velocity at the end of that time.

For each of the following pairs of places, state with reasons, whether the value of 'g' would be exactly the same at both places; if not, state, with reasons, in which of the two places you would expect it to be greater:

a Calcutta and Darjeeling

b Ghana and London

c The North Pole and the South Pole.

19 A body starts from rest and moves with an acceleration of $30\ m/s^2$. How long will it take to acquire a velocity of 480 m/s?

20 A car travelling at 36 km/hr is brought to rest in 10 seconds. Find its negative acceleration (or deceleration).
Give another example of a body moving with a deceleration.

21 a What is meant by 'work' in the scientific sense?
b Why is less work done in pushing an object 1 metre along a smooth horizontal surface than in lifting it vertically through a height of 1 metre?

22 Calculate the work done in joules in each of the following cases. Take 1 kg to weigh 9.8 N.
a A 5 kg mass is lifted vertically through 2 metres.
b A force of 10 N moves a body through 40 cm in its own direction.
c A boy weighing 50 kg climbs up a flight of 20 stairs each of vertical height 20 cm.

23 Give *one* example of each of the following transformations:
a potential energy to kinetic energy.
b kinetic energy to potential energy.
c chemical energy to heat energy.
d heat energy to kinetic energy.
e kinetic energy to heat energy.
f electrical energy to heat energy.
g electrical energy to light energy.
h electrical energy to kinetic energy.
i electrical energy to chemical energy.
j chemical energy to electrical energy.

24 I lift a 1 kg mass to a vertical height of 10 metres. How much work have I done? How much energy have I spent? What has happened to the energy I have spent? Can I recover it in any way?
Use the above situation as a basis for explaining what is meant by the 'conservation of energy'.

25 How many joules are equal to one calorie? Who was it who first determined this value accurately? Give reasons for and against doing away with calories and expressing heat energy in joules. Which reasons do you feel are the more compelling? What is the view of scientists all over the world in this matter?

26 State three ways in which machines can help us, and for each of these three ways give an example of a machine which helps us in that particular way.

27 You have studied the following machines:
(i) the lever (ii) the pulley (iii) the wheel and axle (iv) the inclined plane (v) the gear.
Given below are a list of a number of common devices, each made up of one or more of the above machines. Decide which type of machine each device is, and write the number of that machine

beside the name of the device. If a device is made up of two or more simple machines, write down the numbers of each of the machines in that device.

(*a*) knife blade, (*b*) reel on a fishing-rod, (*c*) wheelbarrow, (*d*) spiral staircase, (*e*) crowbar, (*f*) door knob, (*g*) block and tackle, (*h*) scissors, (*i*) oars, (*j*) steering wheel of a car, (*k*) gangplank for ships, (*l*) nutcracker, (*m*) mechanism for winding up a toy car, (*n*) winch, (*o*) mechanism for changing the torque (turning effect of the wheels) in a car, (*p*) seesaw, (*q*) bicycle pedal and chain system, (*r*) the bicep, (*s*) arrangement which builders use to carry cement etc. up to the height at which they are working, (*t*) tweezers, (*u*) ramp, (*v*) the common balance (*w*) plank up which barrels of oil are loaded on to a truck, (*x*) a chute for sending down goods from a greater height to a lower one, (*y*) a pump handle such as on a tube well, (*z*) a shovel.

28 Calculate the number of times the force got out (viz. the load) is greater than the force put in (viz. the effort) in each of the following cases:

a a lever in which the effort arm is 80 cm and the load arm 5 cm.

b a wheel and axle in which the radius of the wheel is 40 cm and the diameter of the axle is 10 cm.

c a single movable pulley.

d a combination of a single movable pulley and a single fixed pulley.

e an inclined plane whose length is 4 metres and whose vertical height is 80 cm.

29 In a gear system the driving wheel has 10 teeth and the driven wheel 40 teeth. In what ratio is (*a*) the speed (*b*) the torque, converted by this machine?

9

More About Liquid and Gas Pressure

INSTITUTE OF EDUCATION FOR WOMEN
Deptt of Extension Services.
CALCUTTA-27

1. Fluid pressure

The term 'fluid' applies to any substance which can flow, and includes both liquids and gases.

If a hole were made in the side of a beaker which contained water, the water would pour out through the hole and you would have to press on the hole from the outside in order to keep the water in place. You would have to apply pressure from the outside to balance the pressure of the water from inside the beaker. The same thing would happen if you made a hole in the surface of a container in which there was a gas. The gas also exerts a pressure on the sides of its container.

How is this pressure in fluids caused? We shall consider the case of liquid pressure and of gas pressure separately, as the situation is somewhat different for the two.

It is obvious that a liquid exerts a downward force because of its weight. Since a liquid is not easily compressed and its molecules can flow over one another readily, a liquid also exerts a sideways force and an upward force. Thus a liquid exerts force, and therefore pressure, in all directions at any point in its mass. We can prove this by an experiment.

For this experiment we shall need some way of measuring the pressure at a point in a liquid. We shall construct a simple pressure gauge in the following way. Cover the mouth of a thistle funnel with a thin tightly stretched rubber sheet e.g. from a rubber balloon or the bladder of a football. Then connect the stem of the funnel to a U-tube containing mercury with air-tight rubber tubing as shown in Fig. 9.1. When P, the pressure on the rubber sheet covering the mouth of the thistle funnel, is the same as the atmospheric pressure, the levels of mercury in the two limbs will be the same, i.e. A will be at the same horizontal level as B. If P is now increased, the pressure on A will increase and A will move down and B will move up. The greater the increase in P, the more will A move down and B up i.e. the greater will be the vertical difference between A and B. If P was made less than atmospheric pressure, then B, on which the atmosphere is pressing, will move down and A will move up.

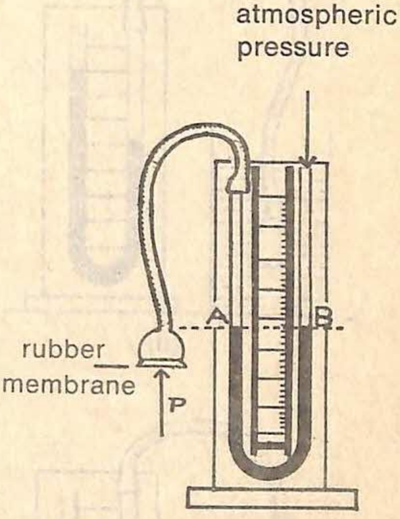


Fig. 9.1 A simple pressure gauge

EXPERIMENT 9.1

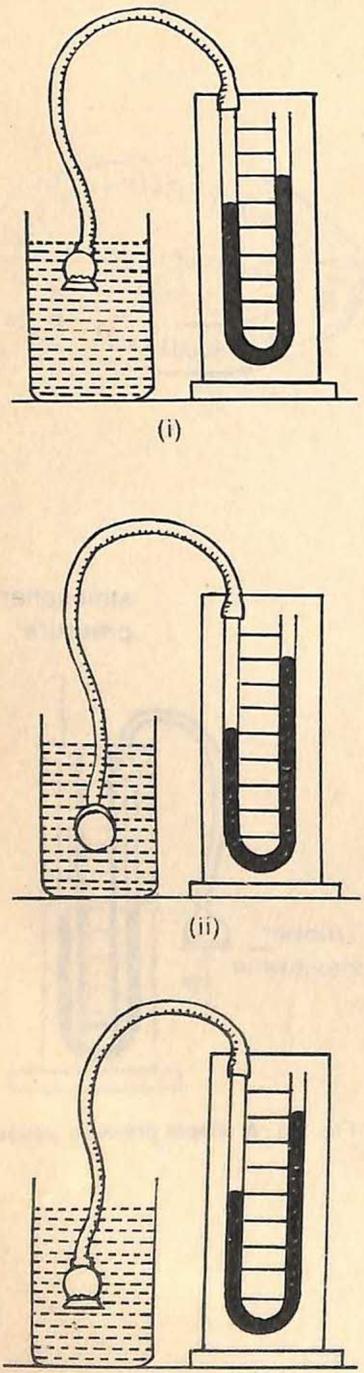
Lower the covered mouth of the thistle funnel into liquid contained in a beaker. (see Fig. 9.2 (ii) and (iii)) Keeping the centre of the circular sheet which covers the mouth at exactly the same position, point the mouth in different directions – downward, upward, and sideways. As long as the centre, or average position of the mouth, remains at the same position the difference in height between A and B remains the same, no matter which way the mouth points. This proves that *pressure at a point in a liquid is the same in all directions.*

The molecules in a gas are very much farther apart than the molecules in a liquid, and are moving with almost complete freedom. The volume of the molecules themselves is very much smaller than the volume of the gas as a whole since the molecules are far apart, and so gases weigh very little, volume for volume, compared with solids and liquids. Because of the very free movement of its molecules any sample of gas resists compression and keeps on increasing in volume until it encounters resistance, as for example from the walls of a container. The molecules hit against and rebound from these walls like hail. Their impact against the walls of the container is the pressure of the gas on the container. Does the push on the wall vary from point to point? If the gas is uniform, and left to itself it will be, the average number of molecules striking equal areas of the walls of the container will be the same everywhere, and the gas will push impartially outward in all directions. This means that in a contained gas, the pressure is the same at all points throughout the gas.

Let us now make two more experiments to investigate the pressure at a point in a liquid.

EXPERIMENT 9.2

Lower the pressure gauge into liquid contained in a vessel. The deeper the mouth of the gauge is lowered into the liquid, the greater the difference in level between A and B. This shows that *pressure at a point in a liquid increases with depth.* (see Fig. 9.2 (i) and (ii)).


(i)

(ii)

(iii)

Fig. 9.2 **To measure the pressure at a point in a liquid**

To explain the increase in pressure with increase in depth, we consider the liquid to be divided into thin layers. The top layer exerts pressure due to its weight on the layer just below it. Both the layers together exert pressure on the layer just below them, and so on. The deeper any layer is, the greater is the number of layers above it, and so the greater will be the pressure on it.

The same reasoning would apply to a large column of fluid e.g. the atmosphere. In a contained mass of gas however the pressure is the same at all points irrespective of their position.

EXPERIMENT 9.3

Lower the pressure gauge down to the same depth, e.g. 20 cm below the surface, in different liquids. It will be seen that the heavier the liquid is, i.e. the greater its density, the greater will be the pressure at that point. This is readily understood from what has been said before. Layers of equal thickness of different liquids have different weights and so exert different pressures, the layers of heavier liquids having greater weight and therefore exerting greater pressure. This experiment shows that the *pressure at a point in a liquid increases with the density of the liquid.*

2. Boyle's Law

Study Fig. 3.10 again. Here we saw that if the pressure of a gas is increased its volume is decreased and vice versa. We shall now go a step further and consider just how much the volume of a gas will change for a given increase in pressure and vice versa. Throughout our discussion we shall consider the temperature of the gas to remain constant, and only consider the volume and the pressure changes, and how they are inter-related.

Consider a certain mass of gas. Imagine its volume to be halved while its temperature remains constant. There are now twice as many molecules in every 1 cm^3 volume than there were before, and consequently twice as many impacts against every 1 cm^2 area of the walls of the vessel i.e. twice as great a pressure. Thus if the volume is halved, the pressure is doubled. Now imagine the volume to be doubled. There will now be half as many molecules in every 1 cm^3 volume than there were before, and consequently half as many impacts against every 1 cm^2 area of the walls of the vessel i.e. half as much pressure. Thus if the volume is doubled, the pressure will be halved. By similar reasoning, it is clear that if the volume is decreased to one third of what it was, the pressure would become three times as great, or if the volume was made $\frac{2}{3}$ times what it was, the pressure would become $\frac{3}{2}$ times what it was. Such a relation in which as one variable increases in a certain ratio the other decreases in the same ratio, and vice versa, is known as an inverse proportion. Expressing what has been discussed above in a single sentence would lead to the following statement:

The volume of a fixed mass of gas is inversely proportional to its pressure, temperature remaining constant.

This relationship was first established by an English scientist, Robert Boyle (1627—1691), and is therefore known as Boyle's Law.

The volume of a gas is measured in m^3 if it is quite large, or in cm^3 if it is a smaller volume. 1 000 cm^3 is referred to as a *litre*.

The pressure of a gas is often measured in the same units as atmospheric pressure viz. in terms of the height of mercury column (as in a barometer) which that pressure can support i.e. in cm of mercury'. Normal atmospheric pressure i.e. a pressure of 76 cm of mercury is referred to as a pressure of '1 atmosphere', and so the pressure of a gas is sometimes measured in 'atmospheres'. There are other units for measuring pressure and we shall study these in our next year's Physics course.

We shall now consider a few examples of Boyle's Law i.e. a few volume-pressure changes of a fixed mass of gas at constant temperature.

Example 1. 500 m^3 of hydrogen gas are measured at a pressure of 75 cm of mercury. What volume will this gas occupy if the pressure is increased to 80 cm of mercury, temperature remaining constant?

Solution. Since the pressure is increased in the ratio $\frac{80}{75}$, the volume will be decreased in the ratio $\frac{75}{80}$, and will therefore become

$$(500 \times \frac{75}{80})\ \text{m}^3 = 468.75\ \text{m}^3.$$

Example 2. 10 litres of air at atmospheric pressure (i.e. at 1 atmosphere pressure) are to be compressed to 2 litres volume. What pressure will be required to do this, assuming the temperature remains constant?

Solution. Since the volume is to be decreased in the ratio $\frac{2}{10}$, the pressure will have to be increased in the ratio $\frac{10}{2}$, and will therefore have to become $1 \times \frac{10}{2} = 5$ atmospheres.

Example 3..In a chemical experiment, 447 cm^3 of oxygen were collected at room temperature and a pressure of 76 cm of mercury. What volume would this quantity of oxygen occupy at the same temperature and a pressure of 57 cm of mercury?

Solution. The pressure is decreased in the ratio $\frac{57}{76}$, and so the volume will increase in the ratio $\frac{76}{57}$, and will therefore become

$$447 \times \frac{76}{57}\ \text{cm}^3 = 596\ \text{cm}^3.$$

3. Pumps

We shall now study a few simple machines which operate on changes in fluid pressure.

Since all these machines incorporate a device known as a valve we shall first explain what a valve is. A *valve* is a device that allows flow in one direction only. See Fig. 9.3(i). Fluid can only flow in the direction indicated by the arrow. It could not flow in the opposite direction as the seal would then close the opening. Fig. 9.3(ii) shows the simplified representation of a valve that we shall use in diagrams.

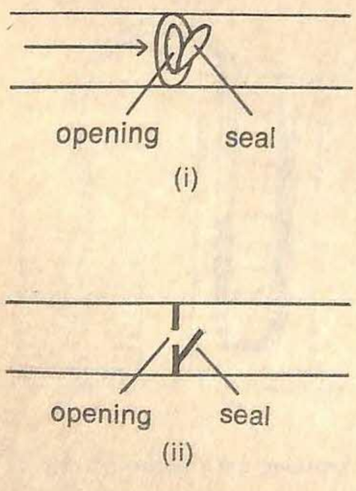


Fig. 9.3 **(i) A hydrostatic valve**
(ii) How we represent a valve in diagrams

The Lift Pump. (see Fig. 9.4) This pump is used to lift water from a tube well up to ground level. It consists of a narrow tube dipping into the liquid to be pumped up, and a broader barrel joined to the tube. An airtight piston or plunger, can be made to move up or down the barrel, by means of the pump handle that works on the lever principle. There are two valves V_1 and V_2. V_1, called the foot valve, is placed where the tube joins the barrel, and V_2 is placed in the piston. Both valves open upwards and close downwards.

When the piston is lowered the air between V_1 and V_2 is decreased in volume and so its pressure increases. This causes V_1 to close and V_2 to open. As the piston moves downward, the air between V_1 and V_2 escapes through V_2, until V_2 reaches the position of V_1.

When the piston is raised the air between V_1 and V_2 is increased in volume and so its pressure decreases. This causes V_1 to open and V_2 to close. The atmospheric pressure P, pressing on the liquid, being greater than the reduced pressure between V_1 and V_2, forces liquid through V_1 into the space between V_1 and V_2.

When the piston is again lowered V_1 is again closed and V_2 opened and the liquid passes through V_2 and collects above it.

When the piston is again raised V_1 is again opened and V_2 closed. More liquid is forced by the atmospheric pressure through V_1, and the liquid which had collected above V_2 is lifted up the barrel and delivered out at the spout.

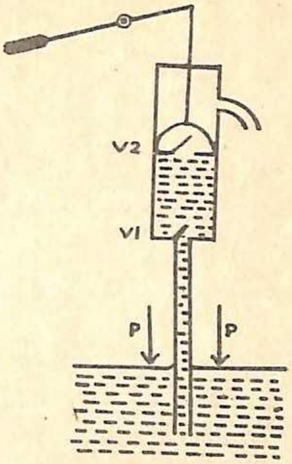


Fig. 9.4 **The lift Pump**

The fact that the liquid is lifted on the piston gives this pump its name. The water comes out of the spout when the handle is lowered because this raises the piston.

It is clear that it is the atmospheric pressure which pushes the liquid up through V_1 into the barrel. Atmospheric pressure at sea-level can, as we have seen, support a column of mercury 76 cm high. Since mercury is 13.6 times heavier, volume for volume, than water, this same pressure could support a column of water 13.6 × 76 cm or 1033.6 cm or 10.336 m high. In practice, mainly owing to leakage between the piston and the cylinder, the vacuum in the barrel is by no means perfect and the water will not rise much more than 7.6 m, and so when this pump is being used to pump water, the foot valve must not be more than 7.6 m above the level of the water in the well.

If any other liquid is being pumped this distance can be calculated in the same way using the density of that liquid. Thus if a liquid like petrol, which is 0.8 times as heavy as water, is being pumped out, the atmosphere can support a higher column of this lighter liquid, and the safe height would then be $\frac{7.6}{0.8}$ m or 9.5 m.

On the other hand if a liquid like sea water, which is 1.02 times as heavy as water, is being pumped out, the atmosphere can support a shorter column of this heavier liquid, and the safe height would then be $\frac{7.6}{1.02}$ m or 7.45 m.

When lift pumps are used for pumping water out of deep wells, the barrel of the pump is placed down in the well shaft. The piston rod is long and can be operated from the top of the well.

The Force Pump. (see Fig. 9.5(i)) The force pump is used for forcing liquid, usually water, to a great height e.g. from storage tanks at ground level to overhead tanks on the top of a high building.

It consists of a barrel and a tube dipping into the liquid to be pumped, and a side tube at the foot of the barrel. A solid piston, without a valve, operates in the barrel. There are two valves. The foot valve V_1 at the junction of the barrel and the tube dipping in the liquid, and valve V_2 at the junction of the barrel and the side tube. V_1 opens upward and closes downwards; V_2 opens away from the barrel and closes towards the barrel.

When the piston is lowered the air between the piston, V_1, and V_2 is decreased in volume and therefore its pressure increases. This causes V_1

to close and V_2 to open and this air is forced out through V_2 as the piston descends to the level of V_1.

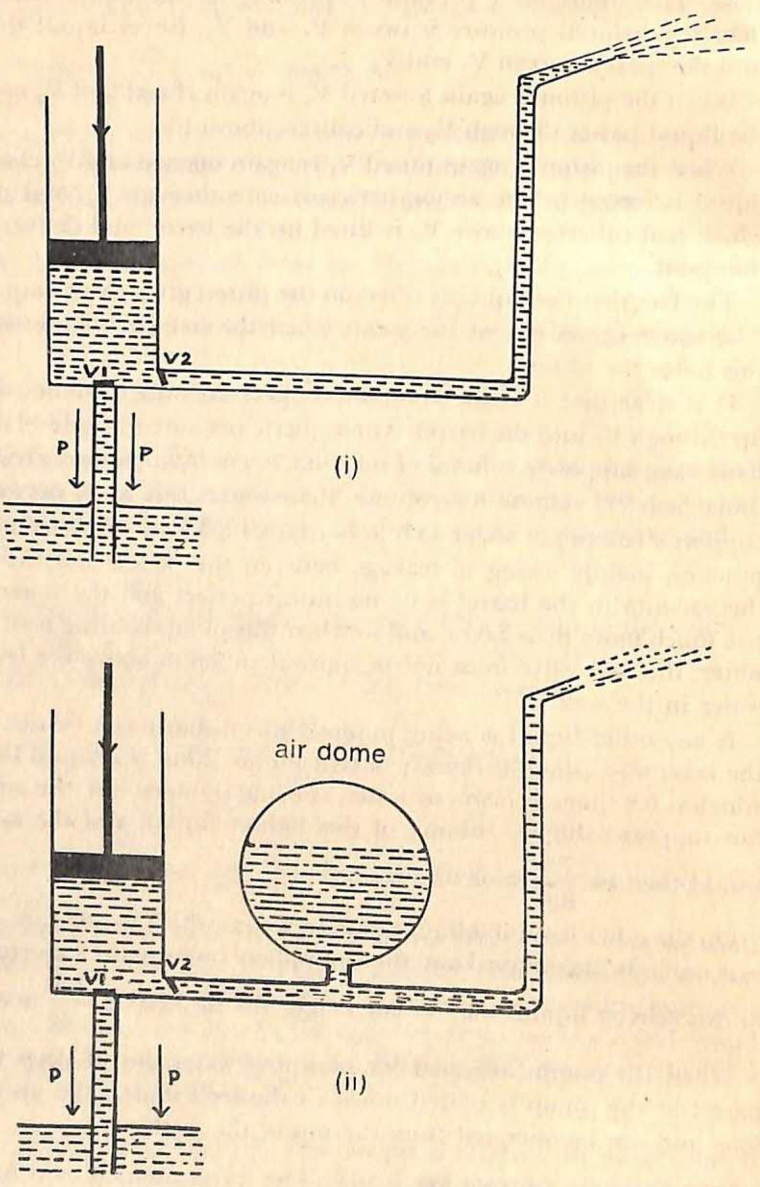


Fig. 9.5 **The Force Pump**
(i) without an air dome
(ii) with an air dome

When the piston is raised the air between the piston, V_1, and V_2 is increased in volume and therefore its pressure decreases. This causes V_1 to open and V_2 to close, and the atmospheric pressure P pressing on the liquid, being greater than the reduced pressure between V_1, V_2, and the piston, forces liquid through V_1 into the space above it.

When the piston is again lowered V_1 is again closed and V_2 opened and the liquid above V_1 is forced out through V_2 into the side tube.

When the piston is again raised V_1 is again opened and V_2 closed. Atmospheric pressure forces more liquid through V_1, and since V_2 is closed the liquid forced into the side tube during the previous downstroke cannot return into the barrel.

Thus on every upstroke more liquid is drawn into the barrel through V_1, and on every downstroke liquid is forced out into the side tube through V_2. This liquid collects in the vertical side tube which may be as high as is consistent with the force available to push the piston down, and the strength of the material which must bear the greater pressure involved.

It is clear that liquid will be delivered out of this vertical side tube only on the downstroke of the piston, and therefore will come out in intermittent spurts. A fairly continuous flow can be arranged by introducing an air dome as shown in Fig. 9.5(ii). On every downstroke liquid is forced out of the vertical side tube, and at the same time liquid rises in the air dome compressing the air in it. On the next upstroke this compressed air releases itself of the greater pressure it acquired in the previous downstroke, and in doing so forces liquid out through the vertical tube. Thus liquid is forced out during upstrokes as well as downstrokes.

Since, as in the lift pump, it is atmospheric pressure which forces the liquid into the barrel through the foot valve V_1, this valve should not be at a greater height above the liquid level than the practical limit of approximately 7.6 m for water, and corresponding heights for other liquids, as explained in the case of the lift pump.

It is interesting to note that the piston rod of a force pump must be short and thick to prevent it from buckling, since the maximum force is exerted on it during the downstroke. In the lift pump, however, the piston rod may be long and thin, since most of the work is done on the upstroke, when it experiences the greatest strain, and so there is no tendency for it to buckle.

The Compressing Pump. This pump is used to pump air into a receiver such as a bicycle tyre tube, a motor car tyre tube, a football bladder, or a balloon.

The basic construction of this pump is shown in Fig. 9.6. A piston works in the barrel. There are two valves: V_1 on the piston and V_2 in the tube. Both valves open towards the receiver and close away from the receiver.

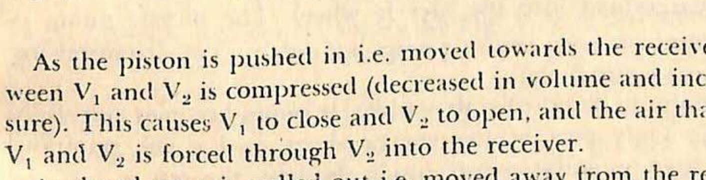


Fig. 9.6 **The Compressing Pump**

As the piston is pushed in i.e. moved towards the receiver, the air between V_1 and V_2 is compressed (decreased in volume and increased in pressure). This causes V_1 to close and V_2 to open, and the air that was between V_1 and V_2 is forced through V_2 into the receiver.

As the plunger is pulled out i.e. moved away from the receiver, the air between V_1 and V_2 is rarefied (increased in volume and decreased in pressure). This causes V_1 to open and V_2 to close. The air that was pumped into

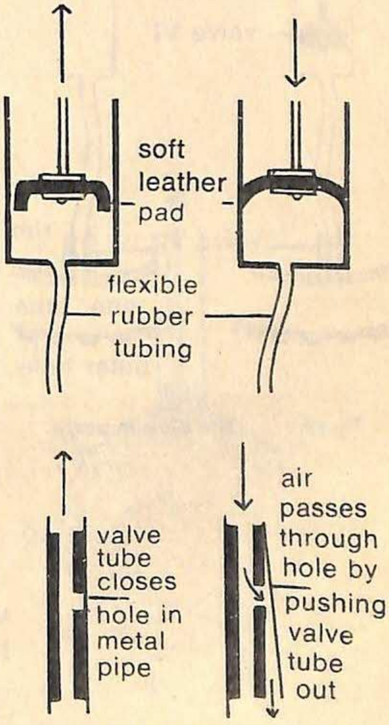


Fig. 9.7
Showing the action of the valves of a bicycle pump

the receiver during the previous 'instroke' cannot return into the barrel since V_2 is closed. Air entering the barrel through the opening A is drawn in through V_1, and during the next instroke of the piston, this air is forced into the receiver.

Thus at every instroke air is pumped into the receiver, and at every outstroke this air cannot return into the barrel, but a fresh charge of air is drawn into the barrel, and this air is forced into the receiver during the next instroke.

The Bicycle Pump. This is a very common form of the compressing pump. Its special features are the design of the valves V_1 and V_2, shown in Fig. 9.7.

V_1 is a soft leather washer slightly larger in cross-section than the barrel. V_2 is not in the pump but in the rim of the bicycle wheel. It consists of a soft elastic rubber tube, known as the *valve rubber* or *valve tube*, tightly stretched over a metal pipe closing a hole in it. The working of the valves is shown in Fig. 9.8.

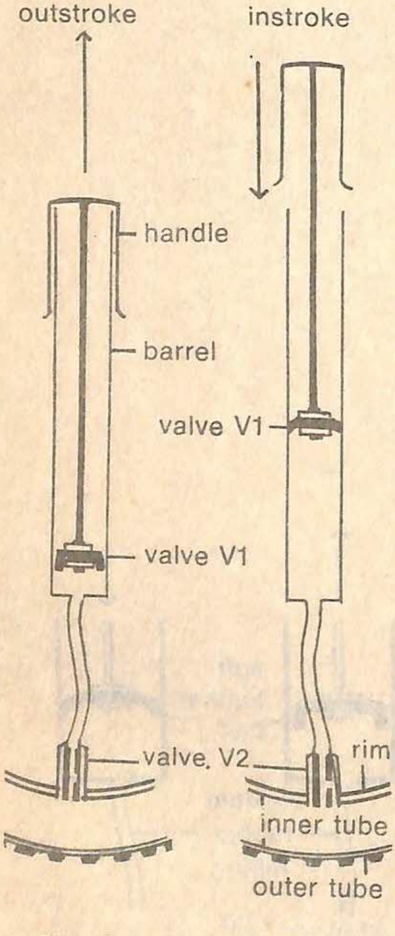


Fig. 9.8 **The bicycle pump**

On each instroke the air between V_1 and V_2 is compressed. This causes the sides of the soft leather washer to be tightly pressed against the barrel which prevents any air escaping past the leather washer, which means V_1 closes. The air between V_1 and V_2 becomes more and more compressed, the piston becomes stiffer to push in, and finally the pressure becomes so great that the soft rubber valve tube begins to bulge outwards leaving a space between itself and the hole in the metal tube, which means that V_2 opens. Air is forced out of the hole, through this space, into the receiver.

On each outstroke, the pressure of the air between V_1 and V_2 drops and air on the other side of the soft leather washer, exerting a greater pressure on it, forces the outer rim of the soft leather washer inwards thus forming a gap between it and the wall of the barrel, which means that V_1 opens. Air passes through this gap into the space between V_1 and V_2. The air previously compressed into the receiver presses on the outside of the soft rubber valve tube with a greater pressure than that with which the air between V_1 and V_2 presses on the inside of it. The soft rubber valve tube is therefore tightly pressed around the metal tube sealing the hole in it, which means that V_2 is closed, and air from inside the bicycle tyre tube cannot return to the space between V_1 and V_2.

Two points are to be noted. The first is that the bicycle pump alone cannot be used to pump air, for example into a balloon. At every instroke air is pumped into the balloon, but at every outstroke it escapes back into the barrel. The reason is that the bicycle pump does not contain the valve V_2. This is incorporated into the bicycle wheel. The bicycle pump is therefore not a complete compressing pump, but only part of a compressing pump; it can never be used alone.

The second point to be noted is that a bicycle pump becomes extremely hot when used. Only part of the energy spent during the pumping is transformed into potential energy inside the tyre; the rest is 'lost', or dissipated, as heat. Why has the word 'lost' in the last sentence been put in inverted commas?

4. Pascal's Law and the Hydraulic Press

We have studied in Volume 1 of this series that if a force is spread out over a large area, the *pressure* it exerts on that area is proportionately reduced. If a metal block measuring 4 cm by 5 cm by 10 cm and weighing 1 600 g is placed on its largest face, its weight will be spread over an area of 50 cm^2, and so there will be a force equal to the weight of 1 600 g (which we shall call a force of 1 600 gf) spread over 50 cm^2 area, and therefore a force of $\frac{1\,600}{50} = 32$ gf on every 1 cm^2 of the area, and we say that the block is exerting a pressure of 32 gf per cm^2, or 32 gf/cm^2, on the surface on which it is resting.

If the block were to be placed on its smallest face it would exert a pressure of $\frac{1\,600}{20}$ or 80 gf/cm^2.

In general if a force F presses down on an area A, the pressure it exerts would be $\frac{F}{A}$. Thus pressure $= \frac{\text{force}}{\text{area}}$, and so *pressure is* defined as *force per unit area.*

Since pressure $= \frac{\text{force}}{\text{area}}$, therefore force = pressure × area. This means that if an area is being subjected to a pressure, then a greater section of the area is subjected to a correspondingly greater force. This is why in the aneroid barometer described in Chapter 3, Fig. 3.17, the partially evacuated box has an undulating, or corrugated, surface. This provides a greater surface area and so the total force exerted by the atmosphere pressing on the box is correspondingly increased. Why do we need to increase this force as much as possible? What other features of construction of the aneroid barometer make this increased force even greater?

A liquid is practically incompressible; a tremendous pressure is required to diminish its volume by a very small amount. If an enclosed liquid is subjected to a pressure, this is transmitted equally throughout the liquid. This can be demonstrated by an ordinary watering can. When the can is tilted, a pressure is developed in the spout by the column of water pressing down on it, and the water issues from each hole in the spout with the same force. Would this happen if the holes were of different size? From which hole, the larger or the smaller, would the water issue with greater force?

A scientist called Pascal made a similar experiment with a syringe ending in a spherical vessel with a number of holes of equal size in it. When this vessel is filled with water and the piston of the syringe is pushed in, water spurts out of all the holes with equal force as shown in Fig. 9.9.

Pascal devised another experiment to demonstrate the transmission of forces through liquids. As shown in Fig. 9.10 it contained two pistons, one of which was one hundred times greater in area than the other. Pascal calculated that since, as shown in the previous experiment, the pressure was transmitted equally in all directions throughout the liquid, then greater areas should have correspondingly greater forces acting on them, and so an area 100 times greater should have a force 100 times as great acting on it, and so if one man were to push on the smaller piston, it would take 100 men to hold the large piston in place.

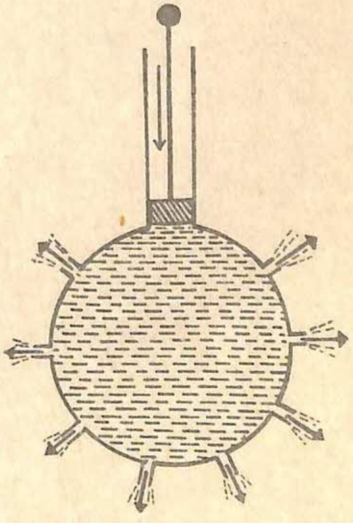


Fig. 9.9 **Pascal's syringe**

From what he concluded from his experiments Pascal stated the principle that is now known as *Pascal's Law* as follows:

When any part of a confined liquid is subjected to pressure, the pressure is transmitted equally and undiminished to every portion of the inner surface of that containing vessel'.

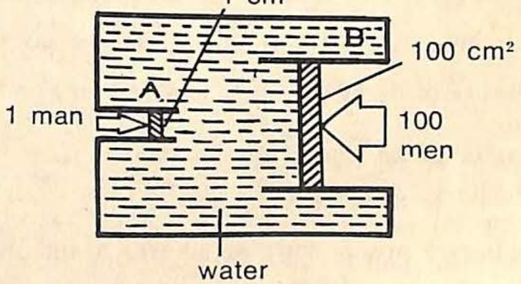


Fig. 9.10 **Pascal's experiment**

The Hydraulic Press (also called the Bramah Press). Pascal's Law is the underlying principle of the hydraulic press, which consists essentially of two cylinders, with air-tight fitting pistons, one of considerably greater area than the other as shown in Fig. 9.11.

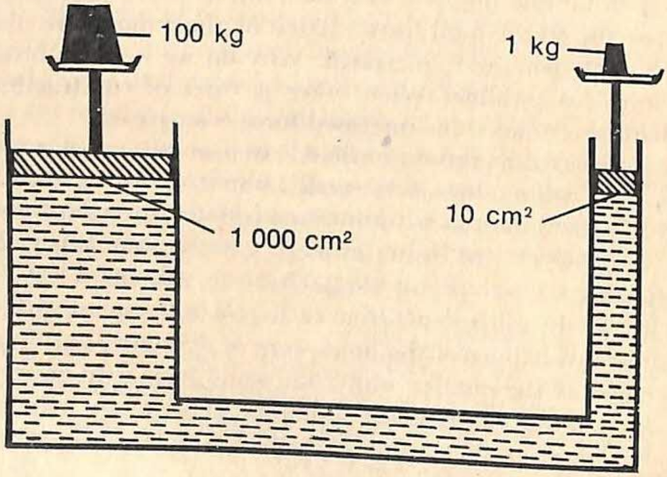


Fig. 9.11 **The Hydraulic Press**

If the pistons are of area 10 cm² and 1 000 cm² respectively, then a force of 1 kgf exerted on the smaller piston would cause a pressure of 100 gf/cm² to be imparted to the liquid contained in the cylinders and the section joining them. This pressure would be transmitted equally and undiminished throughout the liquid so that a force of 100 gf would be exerted on every 1 cm² area of the large piston. Since this has an area of 100 cm², this piston would receive a total force of 100 000 gf, or 100 kgf, and so would exert this force upward on any body in contact with it. Thus a force of 1 kgf applied to the small piston is multiplied into a force of 100 kgf got out at the larger piston.

This greatly increased force can be used to compress raw cotton before it is baled for shipment, to force metal sheet into moulds to make coins, to press plastic materials into hot moulds to make shoe soles, for raising cars so that mechanics and cleaners can work on them from below, for raising dentist's chairs etc.

Questions

1 How would you show by experiment that the pressure at a point in a liquid is the same in all directions? Draw a diagram of the apparatus you would use.

2 Explain, with a diagram of the apparatus you would use, how you would investigate the manner in which the pressure at a point in a liquid depends on (*a*) the depth of the point below the surface of the liquid, (*b*) the density of the liquid.

What would you expect these experiments to show?

3 A quantity of gas is contained in a vessel closed by an air-tight piston. Explain why the gas exerts pressure on the piston. Is this pressure the same as that exerted by the gas on the walls and bottom of the vessel? Explain.

The piston is now raised so that the volume occupied by the gas is doubled. How and why does the pressure change? How would the piston have to be moved in order to increase the pressure to three times its present value?

4 In a chemical experiment conducted at 20°C and 66.5 cm of mercury pressure, 104 cm^3 of carbon dioxide gas were collected. What volume would this gas occupy at 20°C and 76 cm of mercury pressure?

5 A cylinder of internal volume 20 litres contains compressed gas at a pressure of 10 atmospheres. What volume would the gas occupy when allowed to escape into the atmosphere?

6 A gas is contained in a vessel closed by a piston of weight 500 gf and of area 10 cm^2. Taking the pressure of the atmosphere to be 1 kgf/cm^2, calculate the pressure of the enclosed gas. What extra weight should be placed on the piston to reduce the volume of the enclosed gas to three-quarters of its present value?

7 Draw a diagram of the machine used to pump water from an underground well to the surface of the earth. Explain how the machine works. Is there any limit to the depth of the water below the lower valve of the machine? Explain fully.

8 Draw a diagram of the machine used to pump water from ground level to the top of a high building. Explain how the machine works. Is there any limit to the height to which the water can be pumped? Is there any limit to the height of the foot-valve above the water supply? Explain fully. Why is it that the piston rod in this pump must be very thick and strong, while the piston rod of the machine described in Question 7 can be quite thin?

9 Draw a diagram to describe the construction, and explain the working, of a compressing pump. How are the valves constructed in that form of this pump known as the bicycle pump?

Why is it that (*a*) you could not use a bicycle pump to pump air into a balloon, (*b*) the bicycle pump gets very hot during use.

10 State Pascal's Law, and describe an experiment to illustrate the law.

11 Draw a diagram of the essential parts of a hydraulic press, and explain how it works. State three uses to which such a machine can be put.

12 In a hydraulic press the small piston has an area of 20 cm^2 and the large piston an area of 1 000 cm^2. A force of 500 gf is applied to the small piston. Calculate (*a*) the pressure imparted to the liquid, (*b*) the force with which the large piston moves up.

Calculate the force that must be exerted on the small piston to raise a mass of 100 kg on the large piston.

10

Archimedes' Principle

1. The principle

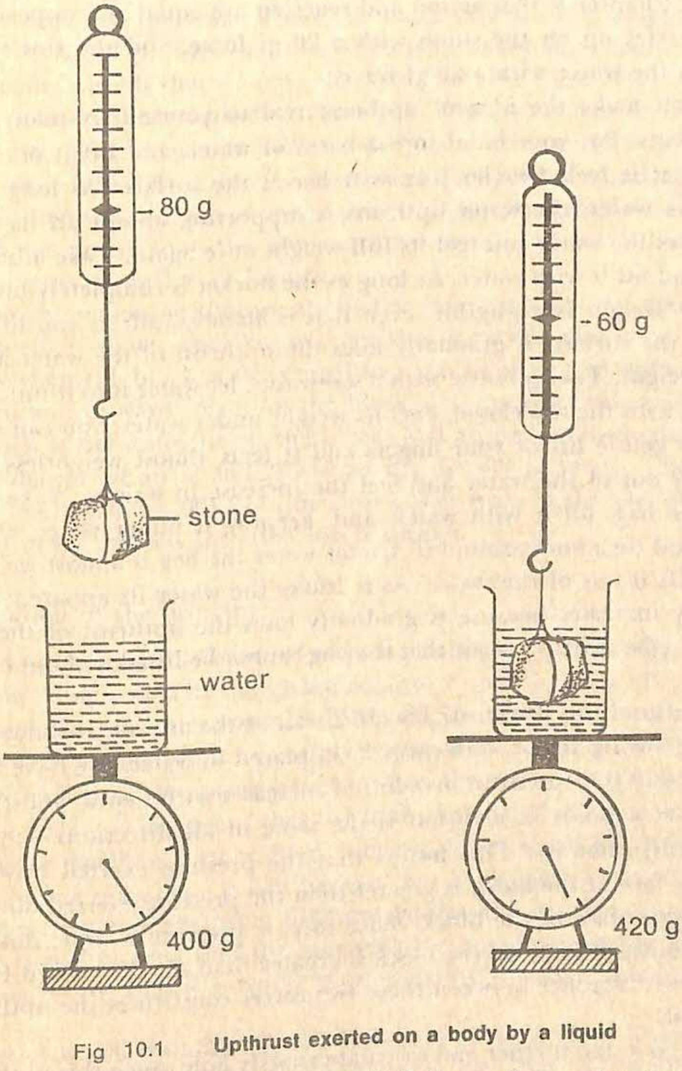


Fig 10.1 **Upthrust exerted on a body by a liquid**

Place a beaker of water on a household balance. Suspend a stone from a spring balance. (see Fig. 10.1). Note the readings of both balances. Now lower the stone gradually into the water in the beaker. The reading of the spring balance will decrease until all the stone is immersed, and then it will remain steady. The stone appears to lose weight when it is immersed in the water, and the apparent loss in weight increases as more and more of the stone is immersed. When we say the body 'loses weight' by immersion, we mean that part of the weight of the body is being supported by something other than the spring balance. We can make a body 'lose weight' in this sense by pushing up on it with our fingers. In this case it must be the water that is pushing up on it, or exerting an upthrust on it. The ability of a fluid to exert an upthrust is called *buoyancy*, and the upthrust is often called *buoyant force*. When the stone is fully immersed, the strength of the upthrust is, in this case, 20 gf. Now take the reading of the household balance when the stone is fully immersed. It will be seen to be 20 g more than the first reading. This illustrates Newton's law stated in Chapter 5, that action and reaction are equal and opposite. The water presses up on the stone with a 20 gf force, and the stone presses down on the water with a 20 gf force.

You can make the idea of upthrust real to yourself by many simple experiments. Put your hand into a basin of water, and lift it out slowly; notice that it feels heavier just as it leaves the surface. As long as it is under the water, the water upthrust is supporting almost all its weight; as it leaves the water you feel its full weight once again. Take a bucket to a pool and fill it with water. As long as the bucket is completely under the water, its weight is negligible, even if it is already full; as you lift it out through the surface, it gradually loses the upthrust of the water and you feel its weight. Take a bottle with a screw top; let water into it until it will just sink with the top closed. Feel its weight under water; you can support it with a gentle lift of your fingers and it feels almost weightless. Lift it gradually out of the water and feel the increase in weight. Take a large polythene bag, fill it with water, and, keeping it under water, close the mouth and tie a knot around it. Under water the bag is almost weightless. Try to lift it out of the water. As it leaves the water its apparent weight gradually increases because it gradually loses the upthrust of the water, and it may be so heavy in air that the bag cannot be lifted without bursting it.

What causes this upthrust? Fig. 10.2 tells us the answer. It shows a glass block measuring 10 cm × 10 cm × 2 cm placed in water. We have learned in Chapter 9 that pressure in a liquid increases with depth, and that the pressure at a point in a liquid is the same in all directions — upwards, downwards, sideways. This means that the pressure exerted upward on the lower face of the block is greater than the pressure exerted downward on the upper face of the block. Since force = pressure × area, this means that the upward force on the block is greater than the downward force on it, and the difference between these two forces constitutes the upthrust of the liquid.

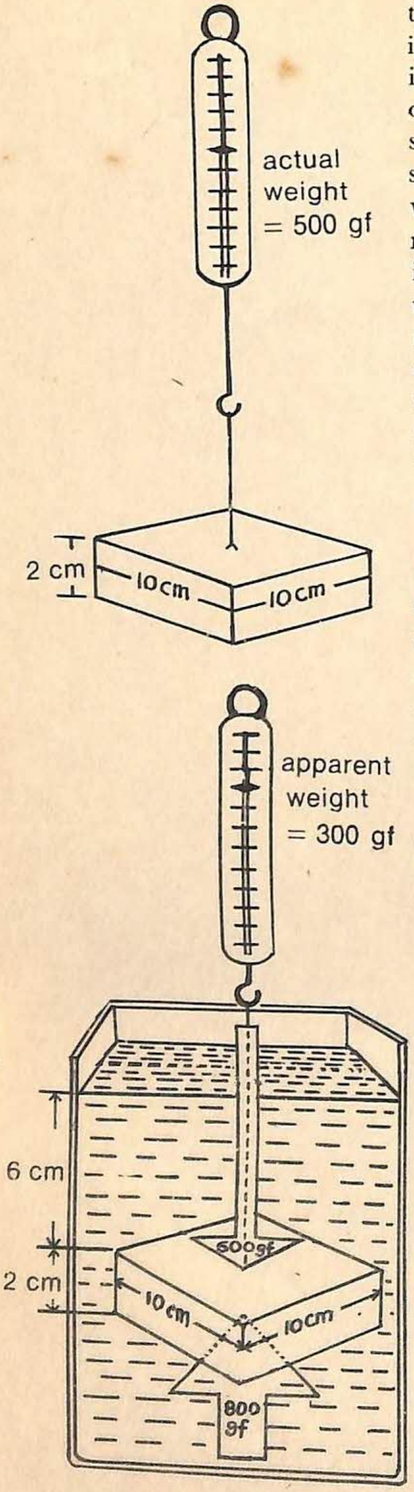


Fig. 10.2 **Cause of the upthrust**

Let us go a step further and calculate exactly how much this upthrust is. The upper surface of the block is 6 cm below the surface of water. This means that there is a column of water 10 cm × 10 cm in area and 6 cm high i.e. of volume 10 cm × 10 cm × 6 cm = 600 cm^3 pressing on this face.

Since the density of water is 1 g/cm^3, this column of water will weigh 600 gf, and will press downward on the glass block with a force 600 gf.

Now let us consider the upward force on the lower face of the block. This face is 8 cm below the surface so that the pressure at any point on this lower face would be that which is due to a column of water 10 cm × 10 cm × 8 cm in volume, i.e. that which is due to a force of 800 gf pressing on that surface. Since pressure at any point at the position of the lower face is the same in all directions, there will be an upward force of 800 gf on the lower face of the block.

An upward force of 800 gf and a downward force of 600 gf reduce to a resultant upward force of 200 gf which is the upthrust.

Now the volume of the block is 10 cm × 10 cm × 2 cm i.e. 200 cm^3. This means that the block moved away, or *displaced*, 200 cm^3 of water which originally occupied the space where the block now is. The weight of 200 cm^3 of water is 200 gf. Note that this is the same as the upthrust.

Archimedes put all that we have discussed into the form of a statement which is known as Archimedes' Principle. This statement in its most complete and general form is '*When a body is immersed either wholly or partially in a liquid or a gas it experiences an upthrust* (and therefore appears to lose weight) *equal to the weight of the fluid displaced*'.

It will be noted that the statement above says that the principle applies to gases as well as to liquids.

Go over the reasoning that we applied to the case when the glass block is suspended in water, and you will see that it would also apply to the situation when the block is suspended in a gas like the atmosphere. The downward and upward forces on the block, and consequently their difference which is the upthrust on the block, will all be correspondingly less since the density of air is .001 293 times the density of water. The forces concerned will each be .001 293 times what they were in the case of water, but in all other respects the situation is similar.

2. Verification of the principle

Suspend a stone from the hook of a spring balance, and read the weight of the stone as indicated by the spring balance. Suppose this is 120 gf. Now lower the stone into water contained in a displacement (or 'Eureka') can, with a beaker placed below to catch the overflow as shown in Fig. 10.3. Take the reading of the spring balance when the stone is fully immersed. Suppose it is 90 g. This means that the upthrust of the water on the stone is equal to the weight of 30 g i.e. 30 gf. Now weigh the water which has been displaced by the stone, and it will be seen that its weight is also 30 gf.

Repeat the experiment using different bodies and different liquids. In each case it will be seen that the apparent loss in weight of the body i.e. the upthrust of the liquid, is equal to the weight of the liquid displaced by the body.

The vessel which contains the liquid in which the body is immersed is known as a *displacement can* or an *'Eureka' can*. Over 2 000 years ago Archimedes was faced with a problem. King Hiero of Syracuse had ordered a gold crown to be made which he wished to present to the Temple of the Gods. The king suspected that his goldsmith had not used all the gold he

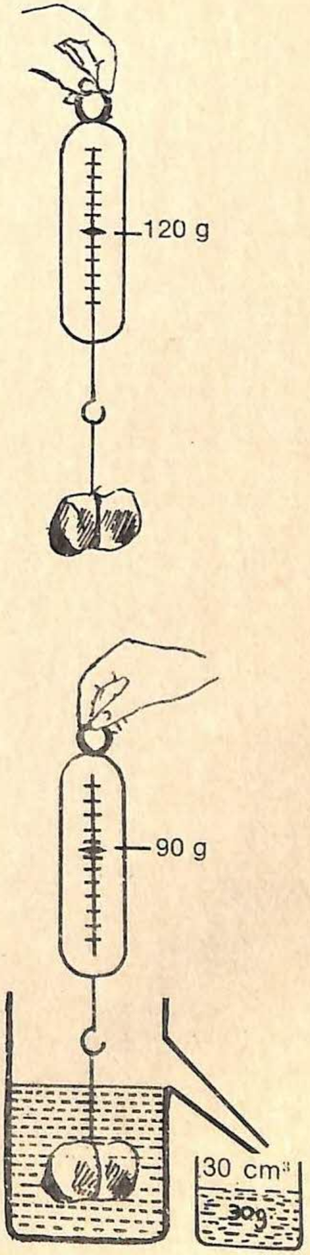


Fig. 10.3
Verification of Archimedes' Principle

4. To find the volume and density of a body by weighing

If a body weighs x gf in air and y gf when fully immersed in water, then its apparent loss in weight due to immersion in water is (x − y) gf. According to Archimedes' Principle this is the weight of the water displaced. Since 1 g of water has a volume of 1 cm^3, (x − y) g of water will have a volume (x − y) cm^3. This, being the volume of the water displaced, is also the volume of the body.

$$\text{Thus volume of body in cm}^3 = (\text{weight in gf of body in air}) - (\text{weight in gf of body in water})$$

Since (x − y) cm^3 of the body weigh x gf

1 cm^3 of the body weighs $\left(\frac{x}{x-y}\right)$ gf,

and the density of the body is $\frac{x}{x-y}$ g/cm^3

$$\text{or, density of body in g/cm}^3 = \frac{\text{weight in gf of body in air}}{\begin{pmatrix}\text{weight in gf of}\\ \text{body in air}\end{pmatrix} - \begin{pmatrix}\text{weight in gf of}\\ \text{body in water}\end{pmatrix}}$$

The idea can be extended to finding the density of a given liquid. Suppose the same body weighs z gf when fully immersed in the liquid, then (x − z) gf is the weight of that volume of the liquid which is displaced by the body i.e. the weight of (x − y) cm^3 of the given liquid.

Since (x − y) cm^3 of the liquid weigh (x − z) gf

1 cm^3 of the liquid weighs $\frac{(x-z)}{(x-y)}$ gf

and the density of the liquid is $\frac{x-z}{x-y}$ g/cm^3.

$$\text{or, density of liquid in g/cm}^3 = \frac{\begin{pmatrix}\text{weight in gf of}\\ \text{body in air}\end{pmatrix} - \begin{pmatrix}\text{weight in gf of}\\ \text{body in liquid}\end{pmatrix}}{\begin{pmatrix}\text{weight in gf of}\\ \text{body in air}\end{pmatrix} - \begin{pmatrix}\text{weight in gf of}\\ \text{body in water}\end{pmatrix}}$$

Problem No. 5 in section 3 above is a numerical example of the above reasoning. Here are some more.

1. A piece of glass weighs 50 gf in air, 30 gf when fully immersed in water, and 32.6 gf when fully immersed in turpentine. Calculate (*a*) the volume of the glass, (*b*) the density of the glass, (*c*) the density of the turpentine.

2. A piece of lead weighs 113.7 gf in air, 103.7 gf fully immersed in water, and 101.1 gf fully immersed in glycerine. Calculate the volume of the piece of lead and the densities of lead and glycerine.

It is clear that the methods of finding volume and density described above can only be applied to non-porous bodies which sink in water or in whatever liquid they are to be weighed in, and which do not dissolve in or chemically react with either water or these liquids.

had been given to make the crown, and had replaced some of it with silver making up the same total weight as that of the gold originally given. The king asked Archimedes to find out whether the beautiful crown was of pure gold or not without destroying it. Archimedes was thinking about the problem as he stepped into his bath one day. Suddenly he realised that just as water overflowed when he stepped into the bath, so he could cause water to overflow by placing first the crown, and then the correct weight of pure gold, in water. If the crown was of pure gold it would have the same volume as an equal weight of pure gold, and would therefore displace an equal volume of water. If the crown was not of pure gold but had some baser metal of different density mixed with it, its volume would be different from the volume of an equal weight of pure gold. Archimedes was so excited by the thought of this discovery that he is reputed to have jumped out of his bath and run naked through the streets shouting 'Eureka, Eureka!' meaning 'I have found it'. He also found that the goldsmith had replaced some of the gold by silver, but the records do not describe the punishment meted out to the wrongdoer.

Displacement cans are often referred to as 'Eureka' cans in memory of Archimedes' historic shouts of glee at making his discovery.

3. Numerical problems

1. A piece of glass of volume 10 cm^3 hangs by a fine thread from a sensitive spring balance; the reading on the balance is 25 g when the glass is hanging in air. What would the reading be if the glass were hanging (*a*) in water of density 1.00 g/cm^3, (*b*) in oil of density 0.8 g/cm^3?

2. A block of iron of volume 175 cm^3 hangs by a thread from a spring balance; the reading on the spring balance is 1.25 kg when the block is hanging in air. What would the reading be if the block were hanging (*a*) in water of density 1 g/cm^3, (*b*) in oil of density 0.80 g/cm^3?

3. A body weighs 6 gf in air and 5 gf when fully immersed in water. Calculate (*a*) the weight of the water displaced, (*b*) the volume of the water displaced, (*c*) the volume of the body. If the body appears to weigh 4.98 gf when fully immersed in salt solution, find the density of the salt solution.

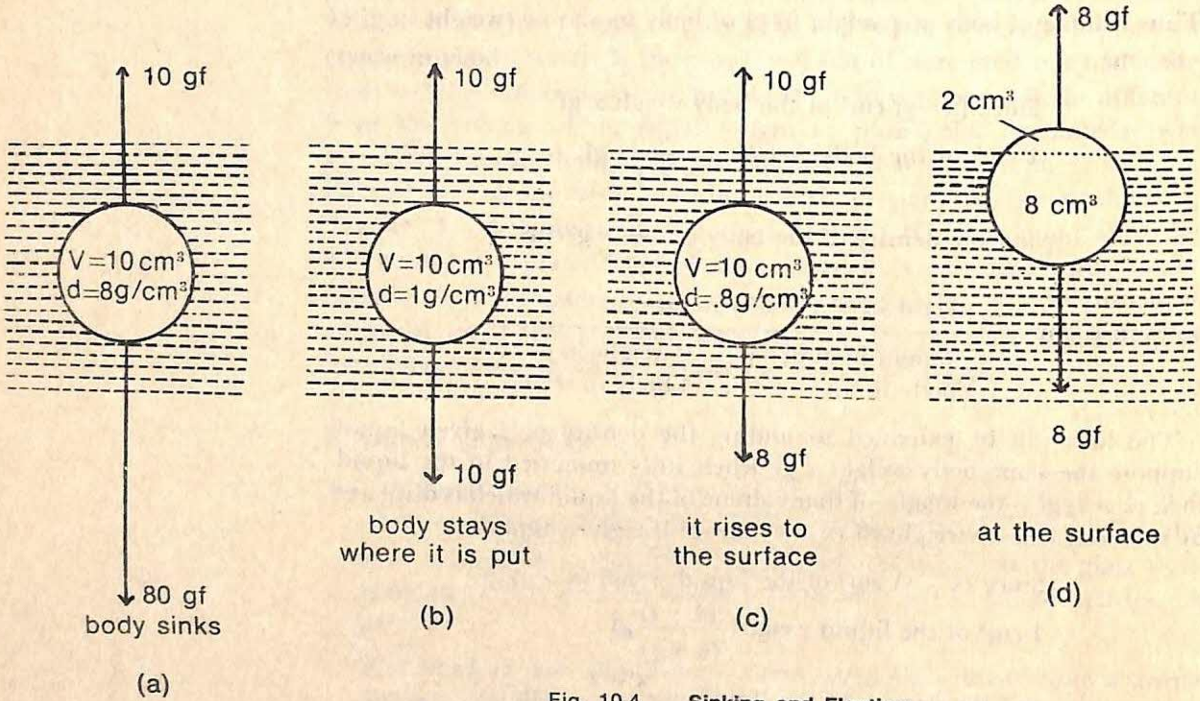
What would the body appear to weigh if half-immersed in oil of density 0.8 g/cm^3?

4. A piece of iron of density 7.87 g/cm^3 weighs 393.5 gf in air. What is its volume? What will it appear to weigh (*a*) when half its volume is immersed in water, (*b*) when fully immersed in a liquid of density of 0.6 g/cm^3?

5. A piece of copper weighs 89 gf in air, 79 gf when fully immersed in water, and 81 gf when fully immersed in alcohol. Calculate (*a*) the volume of the copper, (*b*) the density of the copper, (*c*) the density of the alcohol.

5. Floating and Sinking

Study Fig. 10.4 carefully, working out the calculations given there. Remember that the upthrust is always equal to the weight of the liquid displaced by the body. From Fig. 10.4(a) we see that if the density of the body is greater than the density of the liquid in which it is placed, then the weight of the body downwards will be greater than the upthrust, and the body will sink.



body sinks

(a)

body stays where it is put

(b)

it rises to the surface

(c)

at the surface

(d)

Fig. 10.4 **Sinking and Floating**

Fig. 10.4(b) shows that when the density of the body is the same as the density of the liquid, the weight of the body downwards will be equal to the upthrust, and the body will stay wherever it is put, provided it is entirely immersed in the liquid.

Fig.10.4(c) shows that when the density of the body is less than that of the liquid, the weight of the body downwards is less than the upthrust, and the body will rise to the surface.

Fig. 10.4(d) shows the conditions under which it will float at the surface. Since when it floats on the surface of the liquid, the body is neither moving upward nor downward, its weight must be equal to the upthrust, or in other words *the weight of a floating body is equal to the weight of the liquid it displaces.* This very important fact, known as the Principle of Flotation, is a corollary of Archimedes' Principle.

Application to ships

Until early in the nineteenth century, all boats were made of wood. When boats made of iron were first introduced, many people thought that they would immediately sink because iron sinks in water. How then does an iron ship float while an iron nail sinks? Take an empty tin mug, fill it with water and place it on water in a bath tub. It sinks immediately. Now place the same tin mug empty on the surface of the water. It will float because it is hollow and is able to displace a much larger volume of water than the volume of metal of which it is made. Similarly, because the ship is hollow and can displace a weight of water equal to its own weight, it can float. Every floating ship displaces its own weight of water. This is such a familiar fact to ship designers that the weight of a ship is often given as 'displacement' in tonnes. Thus if a ship has a 'displacement of 20 000 tonnes' this means that when floating it displaces 20 000 tonnes of water, or, in other words, its weight is 20 000 tonnes. If the weight of a ship is increased, because extra cargo has been loaded on, the ship will sink lower so that it can still displace its own weight of water. If cargo is unloaded, the ship will rise in the water. Sea-water has a higher density than freshwater and when a ship sails from a river into the sea it rises higher in the water, because a smaller volume of sea-water is required to be displaced. By international law every ship has a white line painted on the side known as the *Plimsoll line*. This is the safe limit for loading. When a ship has been so heavily loaded that its Plimsoll line is at the water level, no more cargo can be allowed on board, because it is dangerous for a ship to be too heavily laden, as it may sink if it has to sail through rough seas. There is a Plimsoll line marked for freshwater and another Plimsoll line for sea-water. Which is the lower of the two?

It is also dangerous for a ship to be too lightly loaded; it will be top-heavy, and may be blown over on its side by strong winds. For this reason a ship's master always tries to pick up new cargo after he has unloaded some cargo. If he cannot, and must travel with empty holds, he will do so 'under ballast'; that is he will carry a load of stones or rock or any other heavy cheap material, just to keep his ship at a safe loading level, even if he has to throw the ballast overboard when he reaches his destination.

Application to submarines

A submarine is a watertight boat, shaped somewhat like a fish, which can travel under the water. Its engines work from electric batteries or on nuclear energy while it is submerged, and special arrangements are made to keep the air in the submarine fresh for breathing. The submarine has empty watertight compartments or flotation tanks into which sea-water can be pumped. The submarine sinks by allowing sea-water to flow into these compartments; with these tanks full, the average density of the submarine becomes greater than the density of the sea-water. When the submarine has to rise to the surface again, compressed air is allowed to enter the flotation tanks to drive out the water. When these tanks are full of air instead of water, the average density of the submarine is less than that of the sea-water, and it rises to the surface. If the submarine has to remain submerged at a certain depth, it must maintain just enough water in its tanks to give it an average density exactly equal to that of the surrounding sea-water. Study Fig. 10.4 again at this stage, to help you understand more clearly all that has been said.

Every submarine has its own 'maximum depth' below which it must not go. If it goes too low the pressure of the surrounding water is so great (remember that pressure in a liquid increases with depth) that the compressed air available cannot drive the water from the flotation tanks, and the submarine cannot rise after its dive.

One of the most remarkable feats of navigation in recent times has been the journey of the nuclear energy powered submarine *Nautilus* under the ice of the North Pole.

Application to the human body

The human body is made up of bone, blood, muscle and fat, each with its own different density. The average density of the human body depends on the proportion of these constituents and their separate densities, as well as on the amount of air in the lungs at the time under consideration.

When the ribs are out and the lungs are full of air, the volume of the human body is just large enough in proportion to its weight to provide an average density such that the body will float. When the ribs are depressed and the lungs are almost empty the volume of the body decreases and its weight remaining the same its density increases, and the body sinks. The density of the human body with the lungs empty is 1.07 g/cm^3; with the lungs full it is 1.00 g/cm^3. A good swimmer can lie in water, with his lungs partly filled and only his nose and mouth above the surface, and float quite easily. If he struggles or moves, putting a hand or a leg above the surface, the amount of water he displaces will be reduced and the reduced upthrust may not be enough to support him. His face immediately goes below the surface and he has to swim to reach the surface again. A person who cannot swim can float if he keeps calm and lies still, but if he becomes frightened and shouts for help while his mouth is near the water level he may swallow water which increases his weight, and therefore his density, and he will begin to sink.

Why is it easier to float in sea-water than in freshwater?

The Dead Sea, a lake in southern Palestine, is intensely saline. Whereas ocean water has 4–6% salinity which gives it a density of 1.026 g/cm^3, the Dead Sea has 23–25% salinity. This gives it the very high average density of 1.160 g/cm^3, and at its southern end the density is 1.253 g/cm^3. A wader in the Dead Sea finds that when the water reaches his armpits he is swept off his feet, and while swimming his shoulders are all the time out of the water.

Application to fish

Fish live always completely submerged in water. If they were denser than water they would have to move their fins continually to keep from sinking to the bottom. If they were less dense than water they would have to swim to keep below the surface. Either of these two conditions would mean that fish would have to use up energy continually throughout their lifetime and there would be no possibility of rest or sleep. Strangely enough, many species of fish do live throughout their lives in this way. Other species are equipped with an extra organ which provides the answer to the problem. It is called a 'swim-bladder' and corresponds to the 'flotation tanks' on a submarine. This organ is a long, soft-walled sac, into which gases can diffuse from the fish's body fluids. As the bladder fills with gas, the volume of the fish increases, and so does its displacement and the upthrust on it, and the fish can rise through the water since its weight is less than the upthrust on it. As this bladder empties again, the fish becomes slightly denser than the water, and can sink downwards in it. At rest, the swim-bladder adjusts itself until the density of the fish is exactly equal to that of the surrounding water.

Human beings have no swim-bladder, but the lungs act in a similar way making it possible for a person to float if his or her lungs are full of air.

Application to the hydrometer

The hydrometer, shown in Fig. 10.5, is a direct application of the principle of flotation. It is usually made of glass and consists of a large hollow bulb to ensure buoyancy, a smaller weighted bulb to ensure that the hydrometer floats vertically, and a narrow graduated stem. The hydrometer is used to measure the density of liquids. When placed in a liquid, the hydrometer floats displacing its own weight of liquid. The lighter the liquid the greater the volume of it that must be displaced and the deeper the hydrometer sinks. The scale reading on the graduated stem up to which the hydrometer sinks in any liquid indicates the density of that liquid.

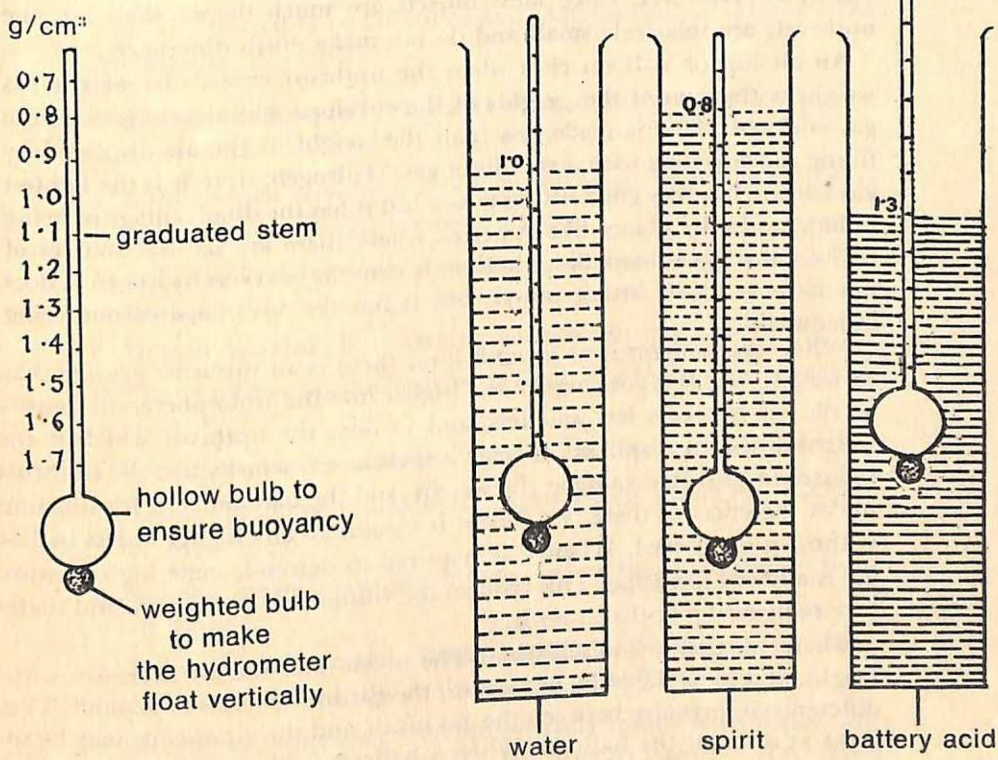


Fig. 10.5 **The hydrometer**

Apart from their frequent use in laboratories, hydrometers are used to test the purity of milk; pure milk should have a density of 1.03 g/cm^3. They are also used to measure the density of the sulphuric acid in accumulator cells; the density of the acid indicates the state of charge of the cell. Hydrometers are also used to measure the strength, or 'proof', of spirits, since the density of the spirit depends upon its strength or 'proof'.

6. Archimedes' principle in gases

Archimedes' principle does not only apply to liquids; it applies to gases as well. Both gases and liquids are fluids, and the principle applies to both. Just as for liquids, the upthrust provided by a gas may be greater than the weight of the body, or equal to it, or less than it. The main difference is that in all normal situations a body is always totally immersed in the gas, and never floating upon it partly submerged, and so it experiences an upthrust due to displacement of its total volume of gas. If the upthrust is greater than its weight, the body will move upwards through the gas; if it is less the body will move downwards through the gas. If the upthrust on the body is just equal to its weight, the body will remain suspended in the gas without moving upward or downward in it.

As all objects on the earth are displacing air, they are all acted upon by upthrusts. However, since most objects are much denser than air, the upthrusts are relatively small and do not make much difference.

An airship or balloon rises when the upthrust exceeds its weight. Its weight is the sum of the weights of the envelope and accessories and the gas enclosed. This is made less than the weight of the air displaced by filling the envelope with a very light gas. Hydrogen, since it is the lightest gas known, has very good lifting power but it has the disadvantage of being inflammable. In places like America where there are natural sources of helium, this gas is used. Since helium is twice as heavy as hydrogen it does not have as much lifting power, but it has the advantage of not being inflammable.

When the balloon is at ground level there is an upthrust greater than its weight, but as it goes higher and higher into the atmosphere, the density of the air becomes less and less, and so does the upthrust which is the weight of the air displaced. A stage is therefore reached when the upthrust reduces to the same value as the weight, and the balloon is in equilibrium under the effect of these two forces. It cannot go any higher unless ballast is thrown overboard. When it is required to descend, some high-pressure gas is allowed to escape. This reduces the volume of the balloon, and therefore reduces the upthrust on it.

There is another complication. The pressure of the air decreases with height, and so as the balloon ascends, the gas inside tends to expand. The difference in pressure between the gas inside and the air outside may be so great as to burst the balloon. When a balloon is being released from the ground it is only partially filled with gas. At the lower pressure of higher altitudes this gas is sufficient to extend the envelope fully.

With the development of jet aircraft for passenger flights, and rockets and satellites for scientific study of the higher altitudes, the use of airships and balloons is becoming obsolete. They are still used however for the study of weather conditions in the upper atmosphere.

Questions

1 What is meant by 'buoyancy'. Give three examples of buoyancy in liquids.

2 Explain, with the help of a numerical example, the reason for the upthrust on a body placed in a liquid.

3 State Archimedes' principle. Explain, with a diagram of the arrangement of the apparatus used, how you would verify Archimedes' principle using a spring balance, a displacement can, a common balance, different solid bodies and different liquids.

4 A block of wood hangs from a spring balance. It is slowly immersed in water in a beaker which is itself standing on a compression (household) balance. Describe and explain the changes you would see in the readings on the two balances.

5 State the principle of flotation, and explain how it follows from Archimedes' principle.

6 Explain each of the following with reference to the physical principles involved:

a A ship which sails from a river into the sea rises higher (i.e. is less submerged) when it enters the sea.

b A ship sinks deeper into the water when more cargo is loaded on to it.

c An iron nail sinks in water, but an iron ship can float on water.

d The markings on the graduated stem of a hydrometer decrease upward.

e How a submarine can descend, or rise, or stay at a fixed depth.

f Submarines have a 'maximum depth' below which it is not safe for them to go.

g Balloons are only partially inflated before they are released from the ground.

h Balloons reach a certain height in the atmosphere above which they cannot rise without throwing out ballast.

i Life-jackets, which are water-proof pads stuffed with kapok, are kept within passenger reach on aircraft which cross large stretches of water.

7 A body weighs 56.5 gf in air and 51.5 gf when fully immersed in water. Calculate the volume and the density of the body. What

would the body weigh when fully immersed in kerosene of density 0.8 g/cm^3?

8 A body weighs 79 gf in air, 69 gf when fully immersed in water and 72 gf in petrol. Calculate (*a*) the volume of the body, (*b*) the density of the body, (*c*) the density of the petrol.

9 A pebble weighs 67.1 gf in air and 46.2 gf when fully immersed in water. Calculate the volume and the density of the pebble.

10 A block of wood of volume 25 cm^3 floats in water with 20 cm^3 of its volume submerged. Calculate (*a*) the weight (*b*) the density, of the wood.

11 A rubber weather-balloon, whose total weight uninflated is 10 gf, is filled with 30 litres of hydrogen. What weight can the balloon lift off the ground? Take the density of hydrogen to be 0.09 g/litre, the density of the surrounding air to be 1.29 g/litre, and neglect the volume of the rubber envelope of the balloon.

12 An airship filled with hydrogen has a volume 100 000 m^3. The envelope and structure weigh 80 000 kgf. Neglecting the volume of the envelope and structure, and using the values for the densities of hydrogen and air given in Question 11, calculate the maximum extra load the airship can lift off the ground.

If the airship was filled with helium of density twice that of hydrogen, by how many kgf would the lifting power be reduced? What would be the advantage of using helium instead of hydrogen to fill the envelope of the balloon?

13 Draw a diagram to show the essential parts of a hydrometer. If the hydrometer can read densities from 1.00 g/cm^3 to 1.10 g/cm^3 show where these two markings will be on the graduated stem. State two uses, outside the laboratory, to which a hydrometer is frequently put.

14 Given an accurate and sensitive spring balance, some thread, a piece of metal, water, and a quantity of kerosene oil, explain clearly how you would proceed to find by experiment (*a*) the volume of the piece of metal, (*b*) the density of the metal, (*c*) the density of the kerosene oil.

11
More About Heat

1. Measurement of Heat

To measure anything we require a unit which is a particular amount of the quantity which we are measuring. For example, in measuring time our basic unit is one second, which is a particular amount of time, and in measuring length our unit is the metre, which is a particular length. A given amount of time is measured by comparing it with the second; if it is twenty times greater than that amount of time which we call one second, then it is 20 seconds time. Similarly, if a particular length is twenty times that length known as a metre it will be a length of 20 metres.

We have said very often that heat is a form of energy. Hence to measure heat we should use the standard unit of energy, and this we have learned is the joule whose symbol is 'J'. But this conception of heat was not established until just over 150 years ago. Heat measurements were started in the eighteenth century, about 200 years ago, when heat was considered to be a form of elusive fluid. A quantity of heat was measured by its effect in raising the temperature of a fixed mass of an agreed substance. For convenience water was chosen as the substance and the following units of heat were devised:

(i) The *calorie* (or gram-calorie), which is the quantity of heat required to raise the temperature of 1 gram of pure water by 1°C.

(ii) The *Great Calorie* or *kilocalorie* which is the quantity of heat required to raise the temperature of 1 kilogram of pure water by 1°C. One 'great calorie' or 'Calorie' (spelt with a capital 'C') is equal to 1 000 calories.

(iii) The *British Thermal Unit*, abbreviated Btu, which is the quantity of heat required to raise the temperature of 1 pound of water by 1°F. It may be remembered that until some years ago in Britain, and in the other English-speaking countries, the unit of mass commonly used was the pound, abbreviated 'lb', and the scale of temperature commonly used was the Fahrenheit scale.

(iv) The *Therm* which is 100 000 Btu. Gas which is sold as fuel is still sold by the therm.

These four units are not as good as the joule for many reasons. Firstly, they are based on the properties of water. Secondly, energy is a unifying principle in Physics, so it is desirable to have one unit for all forms of energy, and not different units for the different forms. The joule was established as the standard for heat measurement in 1948. However, the calorie is much better known and is still in common use. To be precise, it should now be defined as 4.1855 joules. For the present it is necessary to be familiar with both units, and we shall use both in the numerical calculations we make. It must be stressed however that the International System of Units (or SI Units) adopted by an international conference in 1960 has the joule as the only unit of heat, and the use of the calorie is being steadily discouraged until it will be eliminated completely. The Btu and therm should not be used and will not be mentioned in this book.

2. Heat capacity and specific heat capacity

Take a wide metal pan and pour some boiling water into it. Support it above a steady gas flame or an electric heater, and stir it continuously, so that its temperature throughout its entire mass will remain steady at its boiling point. Take three identical plastic cups and mark them A, B and C. Pour 50 g of water at room temperature into A, 100 g of water at room temperature into B, and 50 g of mercury at room temperature into C. Support the cups side by side with their bases just in contact with the hot water as shown in Fig. 11.1, so that they are equally heated. Take the temperature of the liquid in each cup after equal intervals of time, say half-minute intervals. The liquid in each cup should be stirred vigorously with the thermometer before each reading. You will see that the rise in temperature is greatest in C, and least in B.

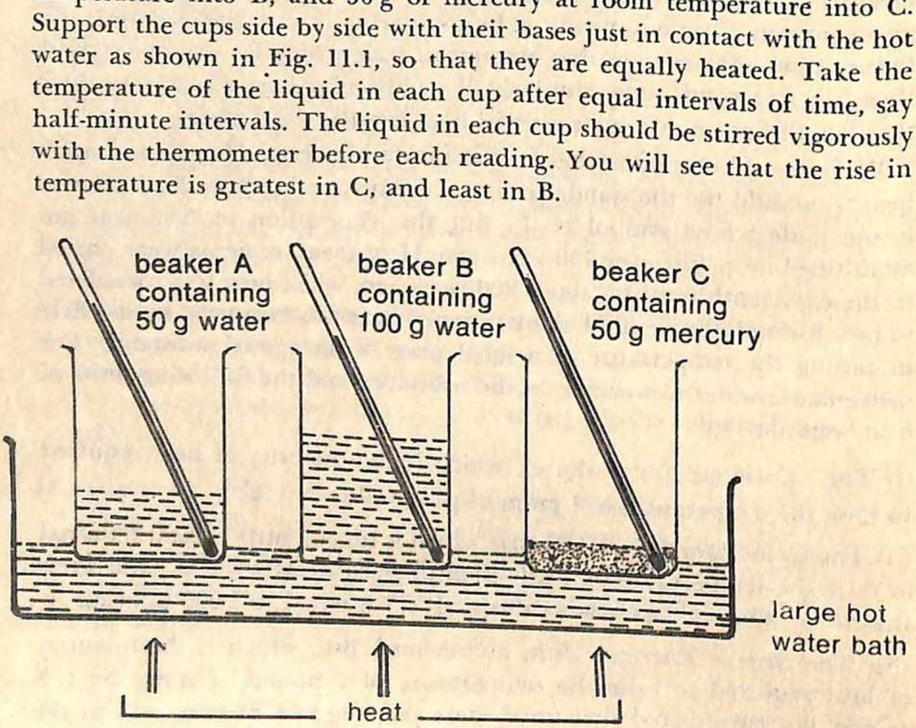


Fig. 11.1 **The effect of heat on different masses and on different substances**

This tells us two things: firstly, that greater quantities of the same substance require greater quantities of heat to raise them through any given temperature interval and, secondly, that equal quantities of different substances require different quantities of heat to raise them through any given temperature interval. *The quantity of heat any particular body requires to raise its temperature through 1°C is called the heat capacity,* *or thermal capacity, of that body*. The units of heat capacity are therefore J/°C or cal/°C. Thus when we say that the heat capacity of a particular body is 10 cal/°C or 42 J/°C, we mean that the body must be given 10 calories or 42 joules (more accurately 41.855 joules) to raise its temperature through 1°C.

Now it is clear that different masses of any one substance will have different heat capacities, and so it would be desirable to have one estimate for that particular substance, which means we should take the heat capacity of a specific mass of it. It has been agreed in the International, or S.I., system that the word *specific* used in front of a quantity shall always have the meaning *per unit mass*. Thus we have the *specific heat capacity* of different substances. *The specific heat capacity of a substance is the quantity of heat required to raise the temperature of unit mass of that substance by 1 degree*. Defined in this way the units of specific heat capacity are J/g °C and cal/g °C, or, more correctly, J/kg °C and cal/kg °C, because the kilogram is the S.I. unit for mass. Thus when we say 'the specific heat capacity of mercury is 0.033 cal/g °C, or 0.139 J/g °C' we mean that we must give 1 gram of mercury 0.033 calories or 0.139 joules to raise its temperature by 1°C. The specific heat capacity values in cal/kg °C and J/kg °C will be 33 and 139, respectively.

'Specific heat capacity' is often referred to as 'specific heat' in textbooks. With the international agreement on the use of the word 'specific' stated above, the addition of the word 'capacity' becomes necessary, and we shall use the term 'specific heat capacity' in this book and throughout this series.

It should also be noted that from the definition of the calorie as the quantity of heat required to raise the temperature of 1 gram of water through 1°C, it follows that the specific heat capacity of water is 1 cal/g °C or 4.1855 J/g °C. Now specific heat capacity as defined above has the unit J/g °C or cal/g °C, but sometimes this unit is omitted. In such cases specific heat capacity is considered as the ratio between the heat requirements of the substance and the heat requirements of water for the same mass and rise in temperature. Thus if it is said that the specific heat capacity of mercury is 0.033, it means that any given mass of mercury to be raised through any given temperature will require 0.033 times the heat required to raise the same mass of water through the same rise in temperature. In this book, and in this entire series, we shall follow the pattern of S.I. units and specific heat capacities will be in J/g °C or cal/g °C, or J/kg °C or cal/kg °C. The specific heat capacities of certain familiar substances are given in the table below:

Substance	**Specific heat capacities**	
	in J/g °C	in cal/g °C
water (at 15°C)	4.1855	1.000
kerosene oil	2.2	0.52
petrol	1.67	0.40
glycerine	2.4	0.58
mercury	0.139	0.033

Substance	Specific heat capacities in J/g °C	in cal/g °C
iron	0.46	0.11
lead	0.134	0.032
copper	0.39	0.093
aluminium	0.92	0.22
glass	0.67	0.16

3. Heat exchange

We have seen that the heat energy of a body is the sum total of the kinetic energy of all its molecules, while its temperature is the average kinetic energy of all its molecules. Thus when a cold and a hot body are brought into contact, the vigorous (hot) molecules transfer some of their energy by collision to the cold molecules until all the molecules in both bodies are moving equally vigorously. In other words heat will flow from the body at a higher temperature to the body at a lower temperature until both are at the same temperature. The point to be noted is that the sum total of all the kinetic energy of all the molecules in both bodies remains the same; some of the energy of the faster moving particles is transferred to the slower moving particles. In other words the heat lost by the hot body is equal to the heat gained by the cold body.

Let us consider a body of mass 'm' and specific heat capacity 's', that is heated through a temperature interval 't'. Let us calculate the heat it has gained. Since the specific heat capacity is 's', this means, assuming that the specific heat capacity was stated in cal/g °C, that:

1 g of the substance to rise through 1°C must be given s cals
m g of the substance to rise through 1°C must be given ms cals
m g of the substance to rise through t°C must be given mst cals

or, in other words, the heat it must gain is

mass × specific heat capacity × rise in temperature.

Similarly if a body of mass 'm' and specific heat capacity 's' were to cool down through a temperature interval 't', the heat lost by it would be

mass × specific heat capacity × fall in temperature.

Both these statements may be combined into the single statement:
heat lost or gained is = mass × specific heat capacity × change in temperature.

The final result will be in joules or calories depending on whether the specific heat capacity is in J/g °C or cal/g °C. If the specific heat capacity is stated in J/kg °C or cal/kg °C, then the value of the mass of the body must be substituted for in kg.

To sum up, in the case of heat exchange between two bodies, there are three points to be noted:

(i) heat will flow from the body at the higher temperature to the body at the lower temperature, till both are at the same temperature,

(ii) the heat lost by the one body will be equal to the heat gained by the other body,

(iii) the heat lost or gained by a body is the product
mass × specific heat capacity × change in temperature.

A few numerical examples will make this clear. The values for the specific heat capacities concerned will be found in the table given above.

1. Find the number of calories required to raise the temperature of 5 kg of water from 20°C to 30°C.

   Answer: $5\,000 \times 1 \times 10$ calories $= 50\,000$ calories

2. Find the number of joules lost when 200 g of iron are cooled from 60°C to 20°C.

   Answer: $200 \times 0.46 \times 40$ joules $= 3\,680$ joules

3. Find the rise in temperature when 1 100 calories are supplied to 50 g of aluminium.

   Answer: mass × specific heat capacity × rise in temperature = 1 100

   $$50 \times 0.22 \times t = 1\,100$$

   $$t = \frac{1\,100}{50 \times 0.22} = \frac{1\,100}{11} = 100°\mathrm{C}.$$

4. A body of mass 600 g requires 660 calories of heat in order to rise in temperature from 110°C to 120°C. Calculate the specific heat capacity of the body.

   Answer: mass × specific heat capacity × rise in temperature = 660

   $$600\,\mathrm{g} \times s \times 10 = 660$$

   $$s = \frac{660}{600 \times 10} = .11\ \mathrm{cal/g}\ °\mathrm{C}.$$

5. How much water at 90°C should be added to 24 kg of water at 20°C to provide a bath at 45°C?

   heat lost by hot water = heat gained by cold water

   mass × specific heat capacity × drop in temperature
   = mass × specific heat capacity × rise in temperature.

   $$m \times 1 \times 45 = 24\,000 \times 1 \times 25$$

   $$m = \frac{24\,000 \times 1 \times 25}{45} = \frac{40\,000}{3}$$

   $$= 13\,333.3\,\mathrm{g} = 13.33\,\mathrm{kg}.$$

Note. In the above situation we have ignored the fact that all the heat lost by the hot water is not gained by the cold water; some of it is lost to the atmosphere. Since we cannot include this heat loss in our calculations (can you suggest why we cannot?), our calculations would be nearer the truth if we brought down this heat loss to an irreducible minimum. This is done by allowing the heat exchange to take place in a vessel which has been so constructed (see Fig. 11.2) as to bring down heat losses to the atmosphere to an irreducible minimum. Such a vessel is known as a *calorimeter*.

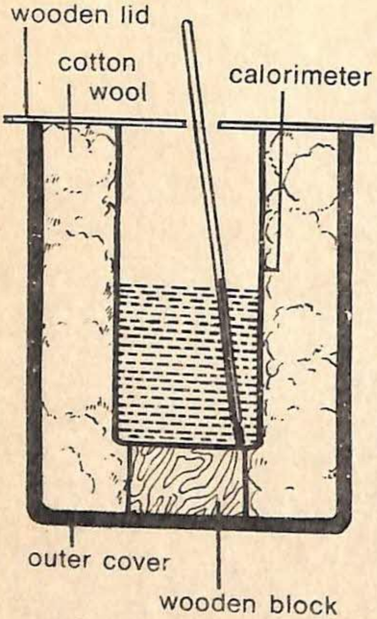


Fig. 11.2 **A lagged calorimeter**

6. A piece of copper weighing 20 g is heated in a flame and then transferred to a copper calorimeter of mass 50 g containing 100 g of water. The temperature of the calorimeter and its contents rises from 28°C to 40°C. Calculate the initial temperature of the heated copper.

Let the initial temperature of the copper be x°C.

$$\begin{aligned} \text{heat lost by copper} &= \text{heat gained by calorimeter} + \text{heat gained by water} \\ 20 \times .093 \times (x - 40) &= 50 \times .093 \times 12 + 100 \times 1 \times 12 \\ 1.86x - 74.4 &= 55.8 + 1\,200 \\ 1.86x &= 1330.2 \\ \therefore x &= 715°\text{C}. \end{aligned}$$

7. A block of aluminium of mass 100 g was immersed in water at 100°C for some time, and then placed in 50 g of kerosene contained in an aluminium calorimeter of mass 35 g. If the temperature of the calorimeter and the kerosene was initially 25°C, and the final temperature of the mixture was 55°C, calculate the specific heat of the kerosene.

$$\begin{aligned} \text{heat lost by aluminium block} &= \text{heat gained by calorimeter} + \text{heat gained by kerosene} \\ 100 \times 0.22 \times 45 &= 35 \times 0.22 \times 30 + 50 \times s \times 30 \\ 990 &= 231 + 1\,500\,s \\ 1\,500\,s &= 759 \\ s &= \frac{759}{1\,500} = .506\ \text{cal/g °C}. \end{aligned}$$

4. Heat (calorific) values of fuels and foods

Heat energy for domestic purposes is often obtained by the burning of fuels such as wood, coal, gas or oil. The heat, in calories, produced by each gram of the fuel in burning is called the *calorific value* of that fuel. Fuels differ in their calorific value; a gram of diesel oil, for example, holds considerably more stored chemical energy than a gram of coal. An engine designer or a factory manager, has to know the calorific value of the fuels he uses so that he can decide how much fuel he will need for a particular job.

In biology, too, the calorific values of foods are very important. Energy is supplied to the body from food which is slowly oxidized, or 'burned', in the process of digestion. The human body is like a machine and food is its fuel. No human being can work unless he or she receives enough food to supply him or her with the energy his or her daily work requires, and enough extra for warmth, growth and repair. It is estimated that the body requires about 3 000 kilocalories or Calories each day. Many of the most valuable foodstuffs, such as green vegetables, fruits or eggs, provide relatively few calories; they are essential for health and growth and for reasons other than the heat energy they supply.

The calorific value of a fuel or a food is measured by means of the apparatus shown in Fig. 11.3. A weighed quantity of the fuel or food, in liquid or powdered form, is put into the small cup in the inner vessel, and enough high-pressure oxygen is pumped into the vessel to ensure complete and rapid burning. The lid is then firmly screwed down, and the inner vessel is lowered into the outer water bath, and the fuel or food is burned by means of an electric spark-gap. The apparatus is sometimes known as a 'bomb calorimeter' because under these conditions almost all fuels burn explosively with a very loud bang. The heat given out by the burning is found by observing the rise in temperature of the water in the outer vessel. Since all the heat produced must either reach this water or stay in the inner vessel, there is no wasted heat and accurate results are obtained by this method.

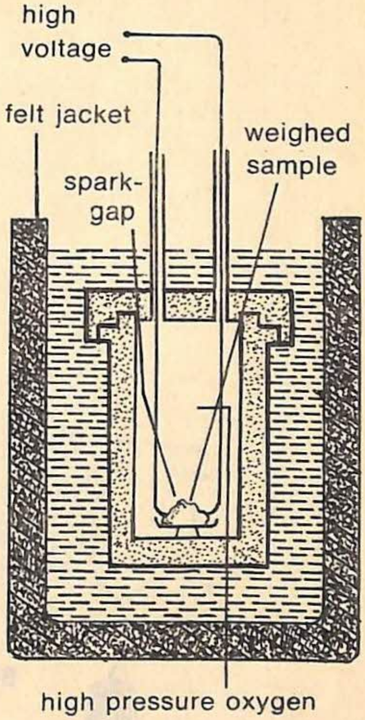


Fig. 11.3

A fuel (or 'bomb') calorimeter

The following is a typical set of results and calculations:

A fuel calorimeter, the product of whose mass and specific heat capacity is 800, is immersed in 2.00 kg of water. 1.50 g of wood sawdust is burnt in the calorimeter, and the temperature of the water and calorimeter rises by 2.36 °C.

We shall calculate the calorific value of the wood from the above information.

$$\begin{aligned}\text{heat given out by burning wood} &= \text{heat gained by calorimeter} + \text{heat gained by water}\\ &= 800 \times 2.36 + 2\,000 \times 2.36\\ &= 2\,800 \times 2.36\\ &= 6\,608 \text{ calories}\end{aligned}$$

1.5 g of wood give 6 608 calories

1 g of wood gives $\frac{6\,608}{1.5} = 4\,405$ calories

Answer: the calorific value of the wood is 4 405 cal/g.

The calorific value of certain fuels and foods is given below:

Fuel	**Calorific Value**	
	J/g	cal/g
Coal	36 960	8 800
Wood	18 480	4 400
Petrol	47 460	11 300
Kerosene	47 040	11 200
Diesel oil	44 100	10 500

Food	Calorific Value J/g	Calorific Value cal/g
Bread	10 500	2 500
Rice	12 180	2 900
Green leaves	1 680	400
Carbohydrate	17 000	4 000
Fat	38 000	9 000
Protein	17 000	4 000.
Milk	2 900	700
Egg	6 700	1 600
Flour	15 000	3 700

5. Change of State

The change from solid to liquid, or from liquid to solid, is known as the lower change of state.

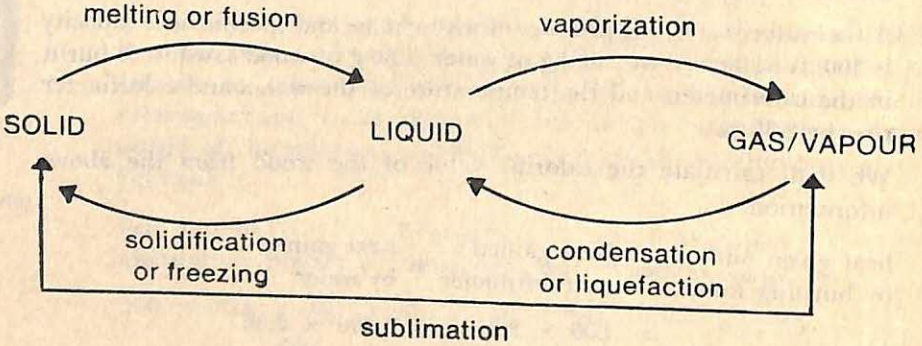


Fig. 11.4 **The terminology of change of state**

The change from liquid to gas or vapour, and the change from gas or vapour to liquid, is known as the higher change of state.

6. The lower change of state

The temperature at which a solid changes to liquid is the same as the temperature at which the corresponding liquid returns to the solid state, and is known as the *melting point* of the solid.

The effect of pressure on the melting point of ice

The melting point of ice is lowered by increase in pressure. This can be demonstrated by a simple experiment. See Fig. 11.5. Take two ice cubes and press them together hard. When released they stick together as one combined mass. When pressed together, the increase in pressure lowers the melting point of ice to below 0°C. The ice which is at 0°C is no longer solid under this increased pressure and melts to water at the area of contact of the two cubes. When the pressure is removed, this water which is at 0°C immediately becomes ice again because the melting point of ice, which is also the freezing point of water, returns to the original value of 0°C. The two pieces of ice now form one continuous piece. The process is known as *regelation*, which means 'freezing again'.

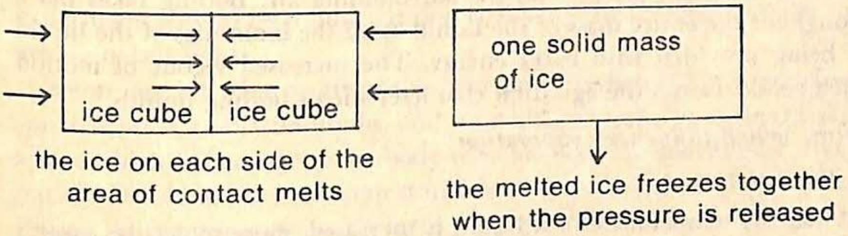

ice cube
ice cube
the ice on each side of the area of contact melts
one solid mass of ice
the melted ice freezes together when the pressure is released

Fig. 11.5 **The regelation of two ice cubes**

Regelation can be demonstrated by another, more striking, experiment. See Fig. 11.6. The wire, because of the great force due to the heavy weight, and because of its small area of contact, exerts a very great pressure on the ice. This lowers the melting point of the ice below 0°C. The ice below the wire, being at 0°C, melts to water, and the wire sinks into the water. The water, now above the wire, being at 0°C immediately freezes back to ice, because the increased pressure which lowered the freezing point is now removed. Meanwhile the wire has lowered the freezing point of the ice now below it, and this ice melts, and freezes back above the wire after it has sunk into the water of the melted ice. In this way the wire passes through the entire block without separating it into two pieces.

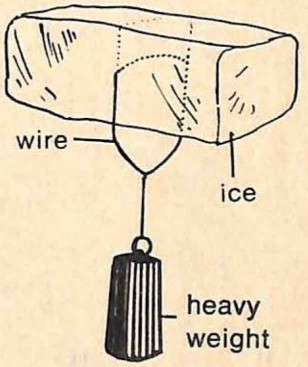


Fig. 11.6 **Weighted wire around a block of ice-Regelation**

7. The higher change of state

Vaporization may take either of two forms: evaporation or boiling. The temperature at which a liquid boils is known as its boiling point. It is the same as the temperature at which the corresponding vapour condenses to liquid.

Distinction between evaporation and boiling

(i) Evaporation can take place at any temperature, some of the molecules at the surface, which are in motion, escaping into the surrounding air. Boiling takes place at a fixed temperature for any one liquid, although, as will be demonstrated later in this chapter, the boiling point of any liquid changes as the pressure on that liquid changes.

Thus water which has fallen on the ground dries up after a while, because it has evaporated i.e. changed into vapour. But water in a kettle on a heater only boils at a certain definite temperature which depends on the pressure exerted on the liquid. This temperature is 100°C at normal atmospheric pressure, but in Darjeeling, where the atmospheric pressure is much less because of its high altitude, water boils at a temperature between 92°C and 93°C.

(ii) Evaporation is a slow change from liquid to vapour; boiling is a rapid one. The change from the liquid to the gaseous state requires that energy be given to the molecules of the liquid. In the case of evaporation this energy is provided at a very slow rate from the surroundings. In the case of boiling this energy is provided rapidly by a strong source such as a heater or a fire.

(iii) Evaporation only takes place at the surface because it is only the surface molecules that can escape into the surrounding air. Boiling takes place throughout the entire mass of the liquid as all the molecules of the liquid are being provided with extra energy. The increased vigour of motion which results causes the agitation characteristic of boiling liquids.

Factors which influence evaporation

(1) *Temperature*

When the temperature of a liquid is increased, more molecules possess sufficiently high speeds to escape from the liquid mass, and so the rate of evaporation is increased.

(2) *Pressure*

When the pressure over a liquid is reduced, the molecules of the liquid can escape more easily from the liquid mass, and so the rate of evaporation is increased.

(3) *Area of surface*

Since it is only the surface molecules that can escape, if the area of the surface of a liquid is increased, more molecules have the opportunity of escaping, and so the rate of evaporation is increased.

(4) *Renewal of the atmosphere*

On a breezy day, take two pieces of cotton cloth, and dampen them equally. Hang one up to dry in the shade of an open verandah where it is exposed to a breeze but not to the direct sun, and hang the other up to dry in a closed cupboard. The cloth in the open air dries far more quickly than the cloth in the closed cupboard. Rates of evaporation must therefore depend partly upon the air which surrounds the drying body. The air around the cloth in the closed cupboard soon became fully loaded, or *saturated,* with all the water vapour it could hold and so evaporation slowed down and stopped because the surrounding air could not hold any more water vapour. On the open verandah, the air around the cloth becomes saturated, or fully loaded with water vapour, but the breeze blows away this damp air, and fresh air which is not saturated with water vapour takes its place, and so evaporation of water from the cloth can continue, and the cloth soon dries.

(5) *Nature of the evaporating liquid*

All liquids do not evaporate at the same rate; ether, petrol, and spirit evaporate much more quickly than water or heavy oil. Liquids which evaporate very fast are called *volatile* liquids. 'Volatile' means 'able to fly'; a volatile liquid seems to 'fly away' into the air.

Cooling caused by evaporation

We have seen that evaporation is the escaping of fast-moving molecules from the liquid mass. This will result in a lowering of the average kinetic energy of the molecules left in the liquid mass, and will produce cooling. The cooling caused by evaporation can be demonstrated by the experiment described in Fig. 11.7. Since ether is a volatile liquid i.e. it evaporates very fast, the cooling is so rapid that the water freezes to ice and the beaker is held fast to the wooden block. Volatile liquids are explosive and so this experiment should be conducted in a well ventilated room in which there are no naked lights.

Before an injection is given the area to be punctured is cleaned with spirit. This is a volatile liquid, and its rapid evaporation cools the skin—a fact which is familiar to anybody who has had an injection or a vaccination. Drinking water is often stored in porous earthenware jars to keep it cool. As the water gradually seeps through to the outside, it evaporates, and this evaporation keeps the water cool.

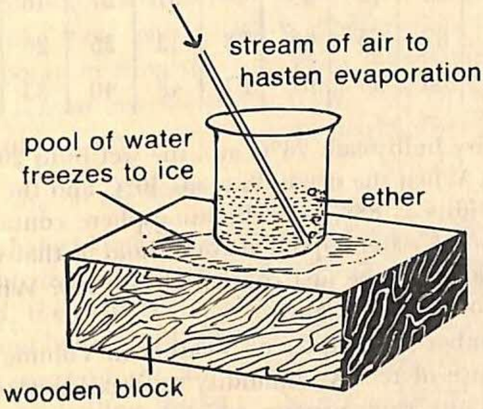


Fig. 11.7 **Cooling caused by evaporation**

The Wet-and-dry bulb hygrometer

This is an instrument for measuring the amount of water vapour present in the atmosphere. We have seen that the more water vapour there is in the surrounding atmosphere the slower will be the evaporation of water into that atmosphere, and the drier the surrounding atmosphere the faster will be the rate of evaporation.

The apparatus, shown in Fig. 11.8, consists of two identical thermometers, the bulb of one of them being covered with a wet cloth. What happens to the reading of this thermometer as the water around its bulb evaporates? What can you say about the quantity of water vapour in the atmosphere when the difference in reading of the wet and dry bulbs is (a) great (b) small (c) zero (i.e. both thermometers read the same)?

The amount of water vapour present in any given atmosphere is usually expressed as a percentage of the maximum amount of water vapour that could be present in that atmosphere. This percentage is called the *relative humidity*, sometimes shortened to *humidity*, of the atmosphere. Thus if the relative humidity of an atmosphere is 64%, this means that the atmosphere contains 64% of the maximum amount of water vapour that it could contain at that temperature.

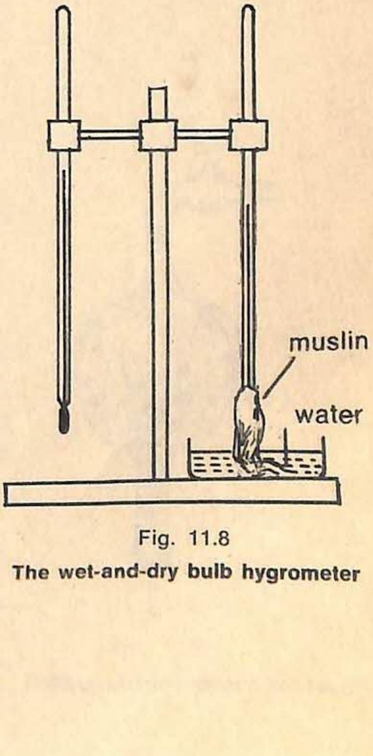


Fig. 11.8
The wet-and-dry bulb hygrometer

The relative humidity can be read directly from prepared tables based on the readings of the wet and dry bulb thermometers. The values given below represent part of such a table, and will give a clearer idea of how the wet and dry bulb hygrometer is used.

RELATIVE HUMIDITY FROM WET AND DRY BULB THERMOMETER READINGS

DRY BULB READING IN °C	DIFFERENCE BETWEEN WET BULB READINGS IN °C									
	0	2	4	6	8	10	12	14	16	18
10	100	77	55	34	15					
16	100	81	63	46	30	15				
22	100	83	68	54	40	28	17	6		
28	100	85	72	59	48	37	27	18	9	
34	100	87	75	63	53	43	35	26	19	12
40	100	88	77	67	57	48	40	33	26	20

Thus when the dry bulb reads 28°C and the wet bulb 20°C, the relative humidity is 48%. When the dry bulb reads 40°C and the wet bulb 38°C, the relative humidity is 88%, i e. the atmosphere contains 88% of the maximum amount of water vapour it could hold at that temperature.

Why are the values in the first column always 100? Why do the values always decrease towards the right?

You will remember the chapter on weather in Volume 1 of this series, where the influence of relative humidity on weather was explained. All ordinary air contains water vapour, which has entered it by evaporation from the sea, from lakes and rivers, from the soil, or from the surface layers of plants or animals. When this atmospheric water condenses again, it forms dew, cloud, mist, rain, hail or snow; all of these supply water to the soil, to rivers and the sea, and to plants and animals. All the water in existence on the earth is thus drawn into one great circulating system or 'cycle'; the state of this cycle at any particular place or time has a very powerful effect on the weather. Remember also the cooling effect of evaporation.

Keeping the body temperature constant

The temperature inside a healthy human body is approximately 37°C and remains constant under a very wide range of conditions.

This temperature maintenance is possible only because the body has ways by which it can generate heat and also lose heat. Heat is produced when food is broken down inside the body; heat is lost mainly by evaporation. These two effects are controlled so precisely that the temperature of a healthy human body rarely varies by more than ½ deg C. The human body provides an example of *thermostatic control*, that is control which keeps the temperature static or still.

The evaporation which cools the body takes place mainly through the skin. The human skin is never completely dry. Sweat is continually passing out to the skin where it evaporates making the skin cool. Heat from the rest of the body is brought to the surface by the circulation of the blood, and thus the whole body is cooled.

During exercise, food substances in the blood are used rapidly by the muscles, and a great deal of heat is produced. This extra heat must be removed, and so sweating therefore becomes more rapid during exercise.

The efficiency of cooling by sweating depends on the relative humidity of the atmosphere surrounding the body. If the air is very dry, sweat evaporates rapidly. Large supplies of drinking water are then needed to keep up the body's supply of fluid, and salt is needed to replace that lost in the sweat. Cooling is efficient if sufficient water and salt is available, and the body can remain healthy and active even if the air temperature is very high.

If the outside air is damp, evaporation is slow, and moisture may gather on the skin; cooling is less efficient. If the air is both very damp and very hot, 'heat stroke' may result; this is a severe fever caused by lack of adequate evaporation from the skin. Even if heat stroke does not result, the condition is most uncomfortable as the body remains hot and covered with a sticky film of sweat which cannot evaporate off.

Effect of pressure on the boiling point

Boiling is a change from liquid to vapour, the molecules of the boiling liquid escaping into the surrounding air. If the pressure of the surrounding air is reduced, the molecules can pass from the liquid to the atmosphere more easily, and boiling will occur at a lower temperature. If, on the other hand, the pressure of the atmosphere is increased, the passing of the molecules of the boiling liquid to the surrounding air is more strongly resisted, and boiling will not take place at the usual temperature but at a higher temperature.

Thus decrease in pressure of the surrounding atmosphere lowers the boiling point, while an increase in pressure raises the boiling point.

(1) *Boiling under reduced pressure*

This can be demonstrated by the following experiment. See Fig. 11.9. Place some water in a round-bottomed flask, with a few porcelain chips to prevent 'bumping'. Bring it to the boil over a bunsen burner or other heater, and continue the boiling until a continuous jet of steam is seen coming from the mouth showing that all the air that was in the flask has been replaced by steam. Remove the burner, and immediately close the mouth of the flask with a rubber bung, fitted with a thermometer. Invert the flask and cool it under a stream of water. The water will stop boiling when the burner is first removed, but a few minutes later it will start boiling again, and will continue to do so even when the thermometer is showing a temperature far below 100°C.

The boiling at low temperature occurs because the pressure in the flask is low. The air was driven out by the steam, and cooling the flask caused this steam to condense thus lowering the pressure exerted on the water inside the flask. This resulted in the boiling point being lowered, and the water started to boil again.

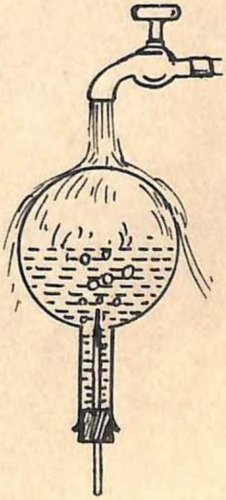


Fig. 11.9

Boiling under reduced pressure

(2) *Boiling under increased pressure*

It is not usually possible to demonstrate this by experiment in the school laboratory, because a very strong and airtight vessel is needed to bear the extra pressure.

The pressure cooker is an application of boiling under increased pressure, and the principle of the pressure cooker is explained in Fig. 11.10. Meat, potatoes, peas etc. to be cooked to a certain degree of tenderness are subjected to a certain temperature for a certain length of time. If they can be subjected to a higher temperature they will reach the required tenderness in a shorter time, and so the pressure cooker enables cooking to be completed more quickly. The materials to be cooked are subjected to a higher temperature because the water and oil in which they are being cooked have their boiling points raised by increase in pressure. As the vapours issue from these liquids they cannot escape, and so they accumulate above the liquids thus increasing the pressure on them, which causes a corresponding rise in their boiling points. If the pressure were to build up too high, it would become strong enough to burst the vessel. For this reason the opening of the cooker is fitted with a safety valve S which will lift at different pressures whose value can be set by adjusting the weights that cover the opening from which the steam escapes. For example if S is adjusted to lift at a pressure 1.67 atmospheres, the water inside the cooker will boil at 115°C, and the food will be cooked at a temperature of 115°C.

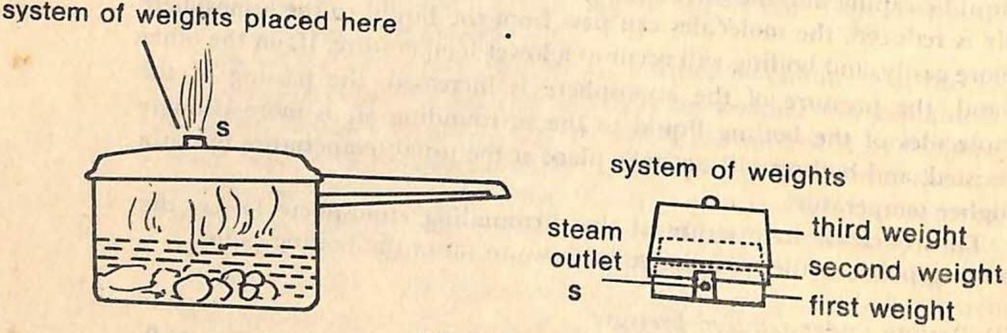


Fig. 11.10

Steam sterilisers used in hospitals for sterilising dressings and instruments, subject these articles to very high temperatures to kill any germs that may be present. The high temperature of the steam is brought about by increased pressure.

Questions

1 Define the 'calorie'. Give two reasons why the joule is preferable to the calorie as a unit of heat energy.

2 What is meant by each of the following statements?:

a 'The heat capacity of a certain piece of iron is 46 J/°C'.

b 'The specific heat capacity of iron is 0.46 J/g °C'. What does the word 'specific' used in front of a quantity like 'heat capacity' mean?

3 a Find the number of joules given out when the temperature of 200 g of water falls by 15°C.

b 1 100 joules are removed from 100 g of kerosene oil at 25°C. Find the final temperature of the kerosene.

4 200 g of water at 90°C were mixed with 400 g of water at 30°C. The final temperature of the mixture was x°C.

(i) Write down the fall in temperature of the hot water, using the symbol 'x'. Thence write down the amount of heat lost by the hot water.

(ii) Write down the rise in temperature of the cold water, using the symbol 'x'. Thence write down the amount of heat gained by the cold water.

(iii) Write down the heat equation: from this equation find 'x'.

5 Find the heat capacity of:

(i) 10 g of iron

(ii) 20 g of petrol

(iii) a body whose temperature rises through 10°C when 500 calories are given to it.

In each case state the units in which your answer is given.

6 An iron calorimeter weighs 600 g, and is initially at 22°C. Water at 95°C is added to the calorimeter, and the final temperature is 62°C. The calorimeter and its contents are found to weigh 680 g.

(i) Find the mass of water in the calorimeter,

(ii) Find the heat lost by this water,

(iii) Using the symbol 's' for the specific heat capacity, write down the heat gained by the iron.

(iv) Write down the heat equation, and from it find the specific heat capacity of iron.

7 A copper calorimeter of weight 150 g contains 100 g of water initially at 22.0°C. A block of metal weighing 255 g is held in water at 100°C for 10 minutes and is then rapidly dried, and transferred to the water in the calorimeter. If the maximum temperature reached by the mixture is 47°C, find the specific heat capacity of the metal.

8 What is meant by the statement 'The calorific value of wood is 4 000 cal/g'? How much heat is released when 2.0 kg of wood is burnt?

Draw a diagram to show the construction of a fuel calorimeter, and explain how it is used to find the calorific value of a fuel or a food.

9 How much oil, of calorific value 11 200 cal/g, must be burned to provide the heat necessary to bring 2 kg of water from 30°C to 100°C?

10 Explain, with reference to the physical principles involved, each of the following:

(i) the boiling point of water in Darjeeling, which is approximately 2.13 km above sea level, is about 93°C, and not 100°C.

(ii) athletes who are sweating profusely protect themselves from draughts.

(iii) pressure cookers enable the cooking to be completed faster than it would be by an ordinary cooker.

(iv) clothes dry faster on a windy day than on a still day.

(v) a rag soaked in petrol dries more quickly than a rag soaked in oil.

(vi) when two ice cubes are pressed together very hard and then released it is found that they have formed one continuous piece.

(vii) in hot climates drinking water kept in a porous pot is cooler than drinking water from a tap.

11 State (*a*) three differences between evaporation and boiling (*b*) four factors which influence evaporation.

In the case of (*b*) explain in terms of the kinetic theory why each of the factors you have mentioned has an influence on the rate of evaporation.

12 Explain in terms of the kinetic theory why evaporation causes cooling, and why condensation causes heating.

Describe the wet and dry bulb hygrometer and explain how it can be used to measure the amount of water vapour in the atmosphere.

13 What is meant by the statement 'the relative humidity of the atmosphere is 67%'? When the wet and dry bulb thermometers read the same what is the relative humidity? Explain.

Why is a hot dry climate far less uncomfortable than a hot humid climate?

14 Describe an experiment, one in each case, to illustrate that:

(i) increase in pressure lowers the melting point of ice,

(ii) decrease in pressure lowers the boiling point of water.

12
More About Light

INSTITUTE OF EDUCATION FOR WOMEN
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CALCUTTA-27

In Volume I of this series we were introduced to 'The Wonderful World of Light'. In Chapter 4 of this book we learned about vision; how our eyes enable us to detect the environment. In this chapter we shall study more about light – this wonderful form of energy which enables us to see and experience all the beauty and colour of our wonderful world.

1. Light travels in straight lines

We can easily understand that light travels in straight lines because we cannot see around corners, and beams of sunlight, which we have often seen in darkened rooms and sometimes in the sky, have straight edges.

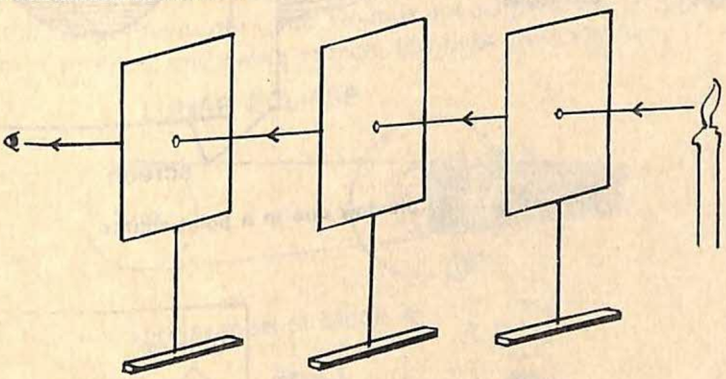


Fig. 12.1 **Light travels in straight lines**

A practical demonstration of the fact that light travels in straight lines, using a flexible tube, was given in Volume I. Here is another. Fig. 12.1 shows three opaque screens each with a pinhole aperture. A candle flame can be seen through the three holes if they are in a straight line. If one of the screens is disturbed so that the three apertures are no longer in a straight line, the candle flame can no longer be seen.

Since light cannot move around opaque objects held in its path, shadows are formed. Fig. 12.2(a) shows the shadow due to a point source, and Fig. 12.2(b) shows the shadow due to a large source.

In Fig. 12.2(a) the area behind the object which is dark because the light from the source is stopped from reaching it by the opaque object, is known as the *umbra* region, 'umbra' being the Latin word for 'shade' or 'shadow'.

In Fig. 12.2(b) the light rays from point P on the source that lie between PA and PB are stopped by the opaque object. The light rays from point Q that lie between QC and QD are stopped by the opaque object. Consider the effect on a screen held at position S_1. The part of the screen above C and the part below B will receive light from all parts of the source and so will be bright. The part between A and D does not receive light from any part of the source, and so will be completely dark i.e. an umbra region. The part of the screen between C and A receives light from the top part of the source but not from the bottom. The part of the screen between B and D will receive light from the lower part of the source, but not from the top. These areas of the screen will therefore be partly bright and partly dark, and are therefore called 'penumbra' which means 'almost an umbra'. What happens to the size of the penumbra when the screen is moved from position S_1 to position S_2 and then to position S_3?

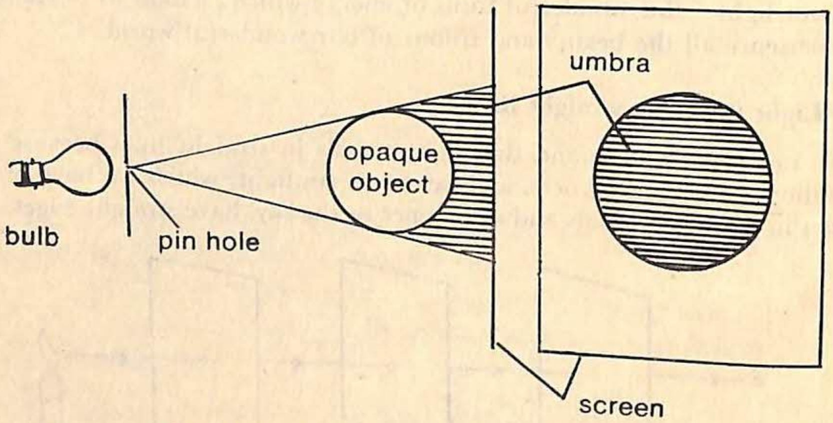


Fig. 12.2 **(a) Shadow due to a point source**

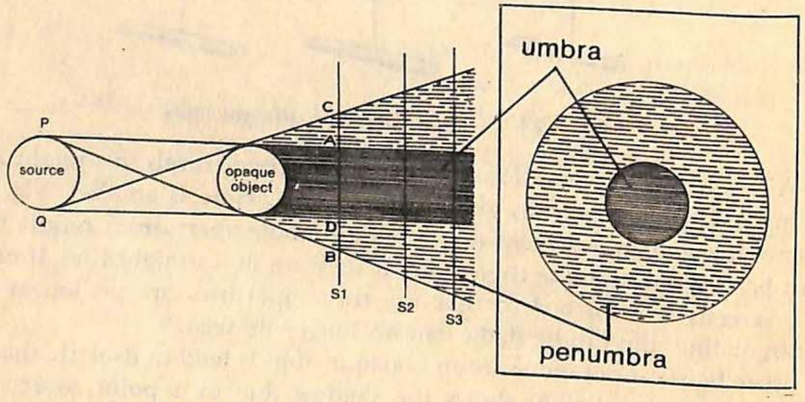


Fig. 12.2 **(b) Shadow due to a large source**

Place your hand between an electric bulb and a white screen e.g. a sheet of paper, in a room that is lit only by that electric bulb. Examine the shadow of your hand. It will be a dark shadow (the umbra) surrounded by a blurred edge (the penumbra). Now gradually move the screen away from your hand. Does the blurring increase in width? Why?

Large opaque bodies like the Moon and the Earth cast shadows, leading to the interesting phenomena of eclipses. The Moon revolves around the Earth while the Earth revolves around the Sun. There will be occasions therefore when the Sun, Moon and Earth are in a straight line, with the Moon between the Earth and the Sun, or with the Earth between the Sun and the Moon as shown in Fig. 12.3 which gives an impression of the movements of the Earth and the Moon. The distances between the different bodies are actually very much greater than can be indicated in the figure. The distance from the Earth to the Sun, for example, should be more than 11 000 times the diameter of the Earth. Furthermore, the diagram gives the impression that the Moon's orbit and the Earth's orbit are in the same flat plane, whereas in actual fact they are tilted at an angle.

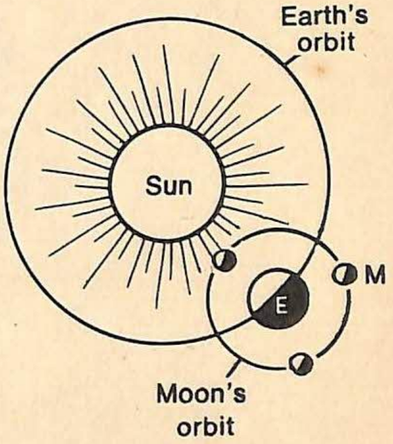


Fig. 12.3 **The Earth's orbit and the Moon's orbit**

The Lunar Eclipse happens when the Sun, Earth and Moon are in a straight line with the Earth between the Sun and the Moon. If the Moon is in the Earth's umbra cone it will not be visible, because the Moon is non-luminous, and can only be seen by the light that falls on it from the Sun, which is now cut off by the Earth. Fig. 12.4 describes the situation. A total eclipse of the Moon is possible because the Earth's umbra cone is wide enough to cover the Moon completely. A partial lunar eclipse occurs when the Moon moves only partly into the shadow or umbra of the Earth. When it is in the Earth's penumbra, the Moon is not eclipsed, but it appears less bright as it receives, and hence reflects, less light from the Sun.

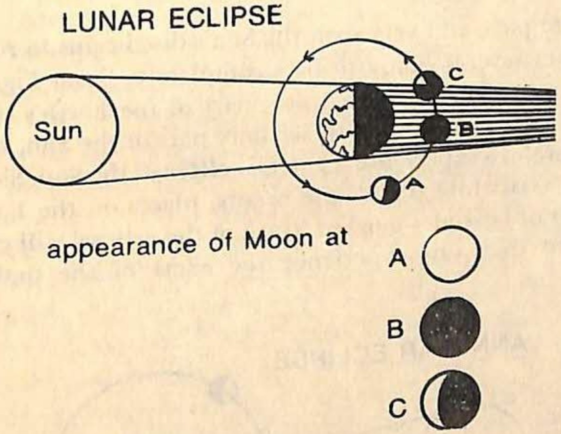


Fig. 12.4 **The Lunar Eclipse**

Astronomers, by measurements and calculations of the paths and speeds of the Earth and the Moon, can tell the dates of lunar eclipses long before they happen, and these dates are published well in advance in almanacs, scientific journals and newspapers. Lunar eclipses happen comparatively frequently and you will have a chance to see one for yourself. The eclipse is visible from all over the world. When it happens, a watcher from the Earth sees the Moon's disc partly hidden by a dark shadow with a curved edge. The Moon gradually moves into the shadow, until the whole disc has become invisible; it may be up to four hours before it moves out of the shadow again. The curved line on the Moon's face at an eclipse is one of the many pieces of evidence that the Earth is round like a ball.

The Solar Eclipse, shown in Fig. 12.5, occurs when the Sun, Moon and Earth are in a straight line with the Moon between the Sun and the Earth. The Earth is much larger than the Moon and cannot fit entirely into the umbra cone of the Moon. People on that part of the Earth's surface that does fit into the Moon's umbra will not see the Sun, so a solar eclipse is a local affair affecting only one part of the Earth at one time. People looking at the Sun from positions in the path of the eclipse will see a circular black patch spreading from one side of the Sun, until, as the edge of the umbra reaches them, the whole disc of the Sun will be hidden and they will be plunged into darkness even though the eclipse may occur at midday. This is called a *total eclipse* of the Sun. It takes only a few minutes for the tip of the umbra to pass, and very soon the Sun's disc begins to reappear. The penumbra takes several hours to pass completely. From Fig. 12.2(b) you will realise that a person situated at a part of the Earth's surface which falls in the Moon's penumbra will see only part of the Sun, but not all of it, and will therefore experience a *partial eclipse* of the Sun. Since the earth rotates on its axis while the eclipse occurs, places on the Earth's surface within the belt of latitudes marked 'track of the eclipse' will come into the position where they can experience the effect of the umbra and the penumbra.

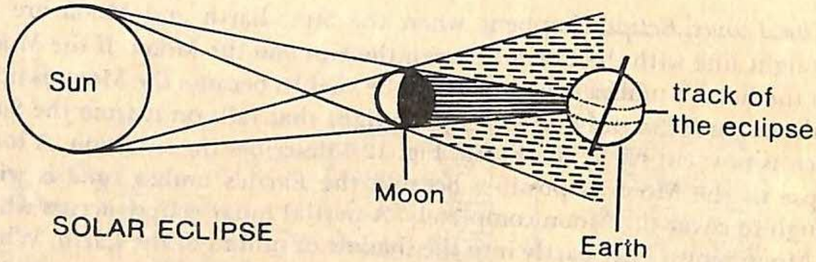


Fig. 12.5 **The Solar Eclipse**

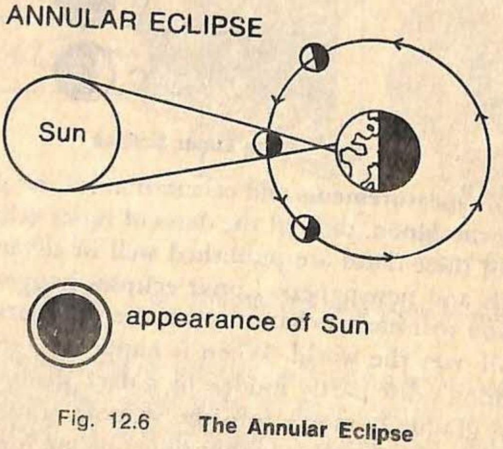


Fig. 12.6 **The Annular Eclipse**

Since the Moon's orbit around the earth is slightly elliptical, its distance from the Earth varies. Thus it occasionally happens that the Moon comes between the Sun and the Earth at a time when its umbra does not reach the surface of the Earth. The situation is shown in Fig. 12.6. People in the centre line of the path of the eclipse will see the Moon lying exactly in front of the Sun but not quite large enough to cover it. They will see a narrow outer ring of the Sun, and this is called an 'annular eclipse', because 'annulus' is the Latin word for 'ring'.

By elaborate calculations scientists can predict beforehand when a solar eclipse is expected. Solar eclipses are quite frequent, but each solar eclipse is only visible over a small part of the world so you may not get many opportunities to see one in your lifetime. Astronomers make use of each eclipse for various scientific observations and measurements. Thus, for example, during a total eclipse of the Sun they can observe the outer atmosphere of the Sun which is ordinarily invisible due to the glare of the Sun.

In Chapter 4, Fig. 4.2, we were introduced to the pinhole camera which is an interesting application of the rectilinear propagation of light (a rather elaborate way of saying that light travels in straight lines).

Take a closer look at Fig. 4.2, and ask yourself what would be the resulting change in the image if (a) the screen were moved closer to the pinhole, (b) the screen were moved farther away from the pinhole, (c) the pinhole aperture were enlarged. It should be quite easy to understand that in (a) the image would be smaller but brighter while in (b) the image would be larger but fainter. To find the answer to question (c) you must realise that the larger aperture would behave like a collection of pinhole apertures, each of which would cast an image. Would these images all coincide exactly? What would be their overall effect?

You may have noticed in the late evening that round patches of light sometimes appear on the inside walls of a closed room or a shed. These patches move upward as the Sun sets. These round patches are pinhole images of the Sun arising from a tiny pinhole or crack in a door or shutter that is facing westward. In full sunlight, pinhole images of the Sun can be seen under leafy trees. The shadow cast by the canopy of the tree is broken by a number of round patches of light. If you look upwards you will see that there are no round holes to account for the round patches. The bright rings are pinhole images of the Sun and may be formed by any very small hole or gap in or between the leaves. The patch is round only because the Sun is round. What would be the shape of these bright patches during a solar eclipse in the periods just before and just after the total eclipse?

2. Reflection of light from plane surfaces

A surface which reflects light *regularly* i.e. according to certain laws, is called a mirror. A mirror whose reflecting surface is flat is called a *plane mirror*. In this section we shall examine the reflection of light from a plane mirror. To do this we shall require an arrangement that will project a forward beam of light. Such an arrangement is called a *ray box* and its construction is shown in Fig. 12.7. The source of light is an electric bulb held in a brass tube which passes through a hole in a sliding top. Its height is adjustable. Rays from this bulb pass through a cylindrical lens. The position of the bulb is adjusted so that a strong parallel forward beam is obtained. There are grooves for pinholes, slits, or coloured plates, and so rays, narrow beams or wide beams of either white or coloured light can be obtained.

Take the ray box with its single slit and place it on a sheet of white paper on a flat table top; the beam will show as a bright line on the white paper. Now take a plane mirror and support it upright on the table top so that the parallel beam falls on the mirror, and observe what happens. Turn the mirror from a position perpendicular to the beam till it makes a very small angle with the beam. Note what happens.

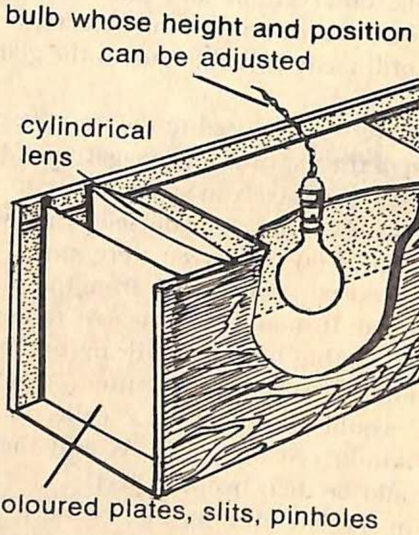

bulb whose height and position
can be adjusted
cylindrical
lens
coloured plates, slits, pinholes

Fig. 12.7 **A Ray Box**

Now mark the position of one sharp edge of the beam from the ray box; this is the *incident ray* ('incident' means 'falling on'). Mark the line of the mirror, and mark the position of the same edge of the *reflected ray*. The two lines marked should meet at a point on the mirror called the *point of contact*. Draw a perpendicular to the mirror from this point; this is called the *normal* to the mirror at the point of contact. Fig. 12.8 shows a typical result of such an experiment. Measure the angle of incidence and the angle of reflection and you will see that they are equal. Repeat the experiment with different angles of incidence and you will see that in every case *the angle of incidence is equal to the angle of reflection*. This is one law of reflection. In what direction would a ray which struck the mirror perpendicularly be reflected? What is the size of the angle of incidence in this case? What should be the size of the angle of reflection?

Now cover the slit with paper in which there is a small pinhole. The light coming from this pinhole will be a single ray. Do this experiment in a darkened room, and you will see that *the incident ray, the normal at the point of contact, and the reflected ray are all in the same plane*. This is another law of reflection.

Although the modern method of using a ray of light produced by a ray box is much more realistic and convincing, the old method of using pins to define rays of light is more convenient in certain cases.

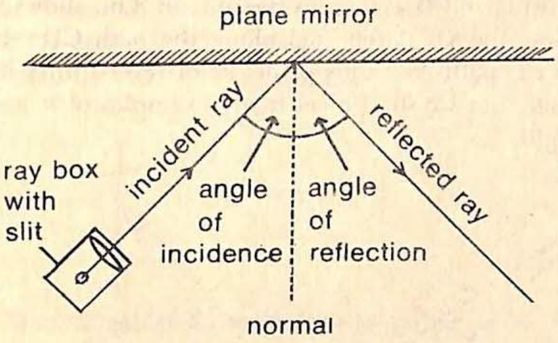


Fig. 12.8 **The laws of reflection**

Pin a sheet of drawing paper to a drawing board, and draw a line XY on the sheet. Place the mirror on this line. Stick two pins A and B vertically into the drawing board. You will see their reflections a and b in the mirror. Sighting along the sheet, place two more pins C and D so that they are in a straight line with a and b. Join AB and CD. When produced they will meet at O on the mirror. Draw the perpendicular ON to XY. Fig. 12.9 shows what you have marked on the drawing paper. Measure the angles AON and DON. They will be found to be equal. Since these are the angles of incidence and reflection respectively, you have verified the first of the two laws stated above.

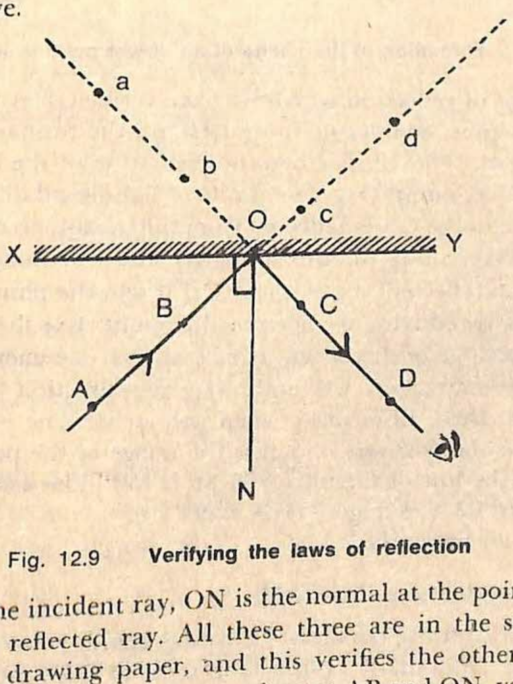


Fig. 12.9 **Verifying the laws of reflection**

Now ABO is the incident ray, ON is the normal at the point of contact, and OCD is the reflected ray. All these three are in the same plane – the flat sheet of drawing paper, and this verifies the other law. If the reflected ray OCD was not in the same plane as AB and ON, you would not have been able to place C and D in the paper when sighting C, D, a, and b in a straight line. You would have had to place them somewhere above or below the surface of the drawing paper.

Now look along AB into the mirror, and you will see that it is in a straight line with C and D as seen in the mirror. This shows the reversibility of rays. The ray AB is reflected along the path CD; the ray CD is reflected along the path AB. This principle of reversibility holds true for any ray or beam, and we shall meet many examples of it as we continue our study of light.

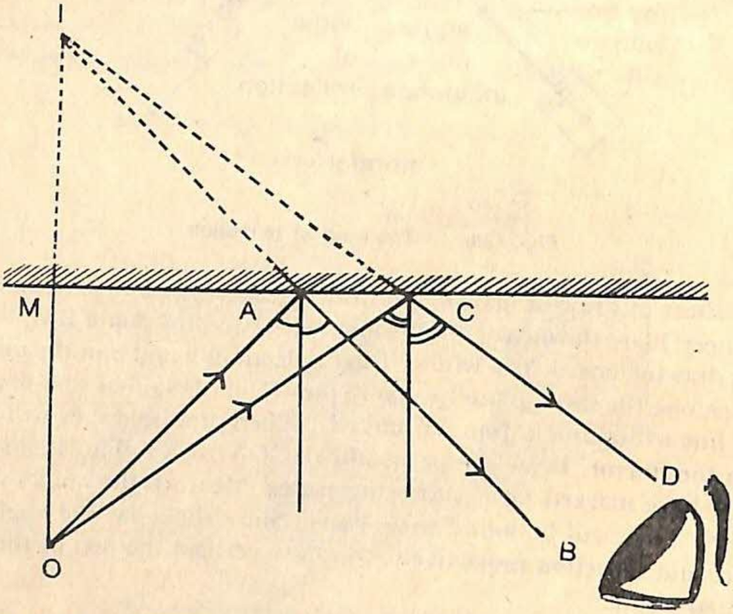


Fig. 12.10 **Formation of the image of an object point in a plane mirror**

The two laws of reflection which we have verified, first with the ray box and then with pins, enables us to understand the formation of an image in a plane mirror. Fig. 12.10 shows the formation of the image of a point object. The object point, O, gives off rays of light in all directions; OA and OC are two such rays. OA is reflected from the mirror, according to the two laws stated above, along the direction AB, and OC along CD. When the eye receives the reflected rays AB and CD it sees the point O, because the light energy it is receiving came from this point. But the eye cannot take into account change of direction; it believes that the energy it is receiving comes along the direction AB, and along the direction CD, i.e. from the point I where these lines meet when produced. The eye therefore sees the point O at the position I, i.e. I is the image of the point O. If IO was joined to cut the line of the mirror at M, it would be seen that IM = OM and that angle IMA = angle OMA = 90°.

This fact can be verified:

(i) *Experimentally* (see Fig. 12.11)

Pin a sheet of drawing paper to a drawing board. Draw a line XY on the drawing paper, and mark a point O in front of this line. Place the mirror along XY, and stick a pin vertically into the drawing board at O. Place three pins A, B, C so that they are in a straight line with the image I of the pin inserted at O. Place three more pins L, M, N also in a straight line with I, and do this again with the pins P, Q, R. Since CBA, NML and RQP all point to the position I, when the mirror is removed and these three lines are produced they will all meet at I, and this locates the position of the image. Join OI and call M the point where it cuts XY. On measurement it will be seen that OM = IM and that angle OMY = angle IMY = 90°.

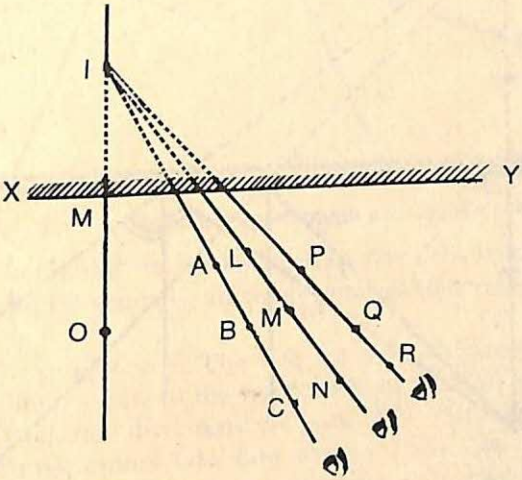


Fig. 12.11 **Experimental location of the image**

(ii) *Geometrically* (see Fig. 12.12)

Since angle of incidence = angle of reflection

angle OAN = angle NAB

or, $i = r$.

but, $i = a$ (alternate angles)

and $r = b$ (corresponding angles)

$\therefore\ a = b$

Now the ray OM which strikes the mirror perpendicularly will be reflected back perpendicularly from the mirror, and we have already discussed why. This establishes that angle OMA and angle IMA are each 90°. In triangles OMA and IMA,

angle a = angle b (proved above)

angle OMA = angle IMA = 90° (proved above)

side MA = side MA

thus the triangles OMA and IMA are congruent (A.A.S.) and therefore OM = IM. We have therefore established that *the image point is on the perpendicular to the mirror line from the object point, and as far behind the mirror as the object point is in front of it.*

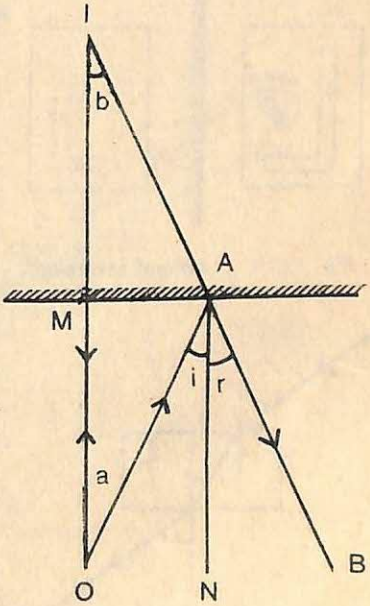


Fig. 12.12 **Geometrical period for the image position**

We can now understand the formation of the image of a body in a mirror. Fig. 12.13 explains this. The object AB consists of many points. Each point on the object has a corresponding image point which is on the perpendicular to the mirror from the object point, and as far behind the mirror as the object is in front. All these image points constitute the image A′ B′.

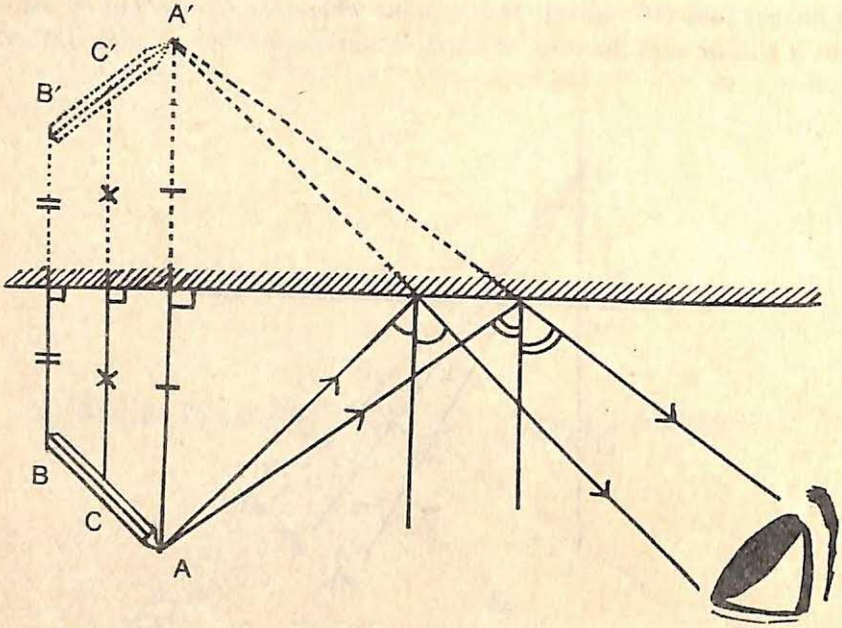


Fig. 12.13 **Formation of the image of an object in a plane mirror**

The position of the image as established above also explains the *lateral inversion* of the image in a plane mirror. Stand in front of a mirror and raise your right hand. Which hand does your image raise? Which hand of the image is on the perpendicular to the mirror from the hand you raised? Write an 'L' on a card and place it in front of a mirror as shown in Fig. 12.14. Explain the appearance of the image in terms of the position of the image as stated above.

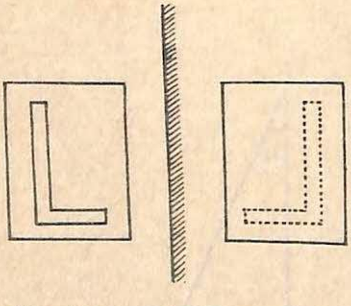


Fig. 12.14 **Lateral inversion**

3. Refraction of light

When a ray of light passes from one substance into another substance of different density, it changes its direction. Such change of direction is termed *refraction* which literally means 'bending back'. Let us examine the passage of a ray of light through a rectangular glass block, and through a triangular glass prism. This can be done by the pin method as shown in Fig. 12.15 and 12.16 respectively, or by the ray box method, which would show the same changes of direction as the pin method shows.

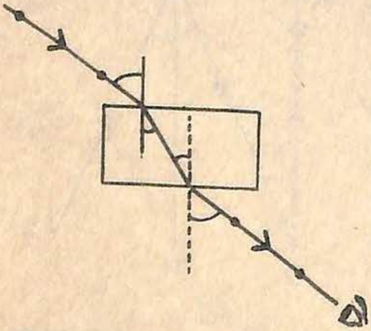


Fig. 12.15 **Tracing a ray through a rectangular block**

The results indicate that *when a ray of light travels from a rarer to a denser medium it is bent towards the normal, and when it travels from a denser to a rarer medium it is bent away from the normal.*

This helps to explain a very well known phenomenon – the raising effect of refraction. A bucket of water looks more shallow than it actually

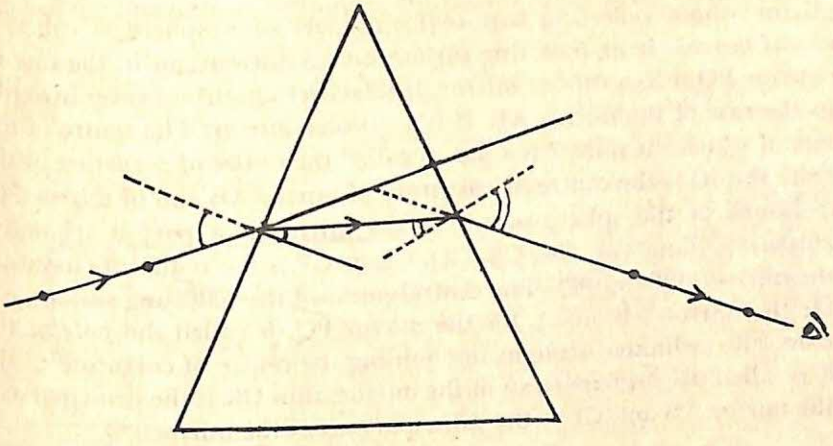
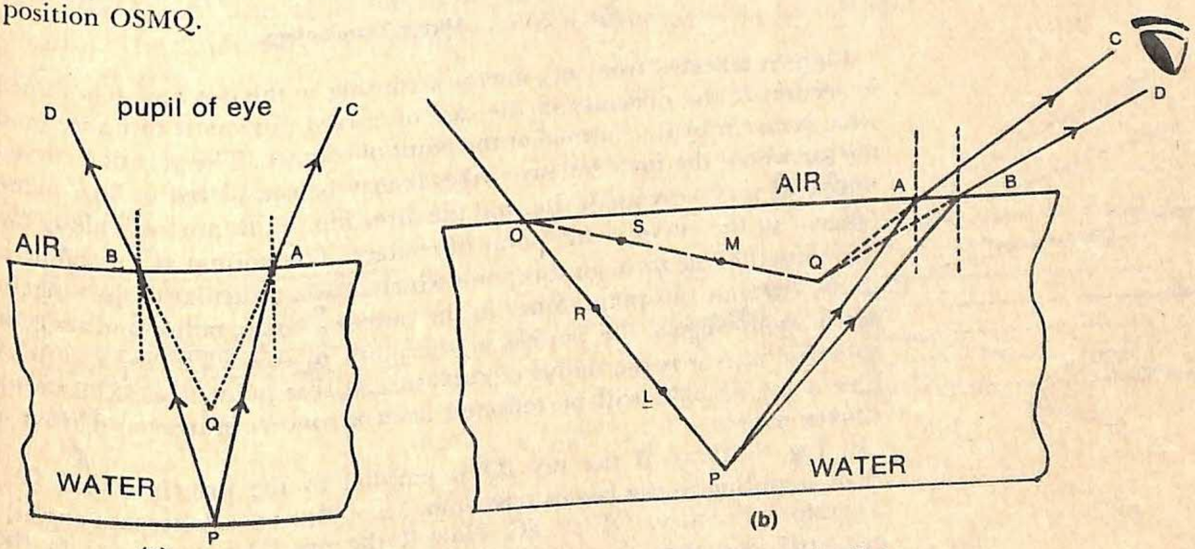


Fig. 12.16 **Tracing a ray through a triangular prism**

is because the bottom of the bucket appears raised by refraction. See Fig. 12.17(a). A stick held slantwise in water appears bent where it enters the water.

Fig. 12.17(b) explains why. The rays PA and PB, when passing from the denser medium, water, to the rarer medium, air, are bent away from the normal along the directions AC and BD respectively. The eye receiving these rays, cannot take into account their change of direction, and sees the point P from which the rays came at the position Q.

Thus the bottom of the bucket appears raised to the level of Q, while in the case of the stick each point in the section under water appears raised, P to Q, L to M, R to S, so the section ORLP appears to be in the position OSMQ.



(a) (b)

Fig. 12.17 **(a) (b) The raising effect of refraction**

How many other examples of apparent raising by refraction can you think of? On the basis of Fig. 12.17(a) and (b) draw ray diagrams to explain these cases.

4. Reflection from spherical mirrors

A mirror whose reflecting surface forms part of a sphere is called a *spherical mirror*. If its reflecting surface bulges outward, as in the case of the mirror PQ, it is a *convex mirror*. If its reflecting surface caves inwards, as in the case of the mirror AB, it is a *concave mirror*. The centre of the sphere of which the mirror is a part is called the *centre of curvature* of the mirror; thus C is the centre of curvature of mirror AB and of mirror PQ. The radius of the sphere of which the mirror is a part is its *radius of curvature*. Thus CA, CK, CB, CQ, CL or CP is the radius of curvature of the mirrors AB and PQ. The central point of the reflecting surface, e.g. K for the mirror AB and L for the mirror PQ, is called the *pole* of the mirror. The unlimited straight line joining the centre of curvature to the pole is called the *principal axis* of the mirror; thus CK is the principal axis of the mirror AB and CL is the principal axis of the mirror PQ.

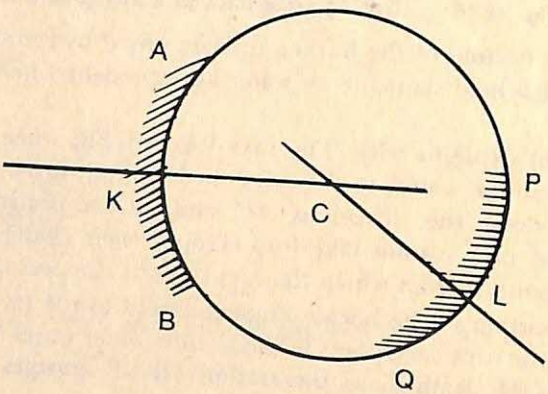


Fig. 12.18 **Mirror Terminology**

Light is reflected from any mirror according to the two laws established in section 2; the difficulty in the case of curved mirrors is to understand what is meant by the 'normal at the point of contact'. The part of a curved mirror where the incident ray strikes it may be considered to be a plane mirror of very, very small size, and the direction of this mirror is along the tangent to the curve at the point of contact. The normal at this point is therefore the line through this point which is perpendicular to the tangent to the curve at this point. Since in the case of a circle, radius and tangent are at right angles, the normal at the point of contact in the case of a spherical mirror is the radius of curvature at that point. Fig. 12.19 shows how a ray of light will be reflected from a concave mirror and from a convex mirror.

In Fig. 12.19(a), if the ray IO is parallel to the principal axis PC, then according to the law of reflection, i = r. But i = a (alternate angles). Therefore r = a, so OF = FC. Now if the ray IO is very near to the principal axis, then O will be very near P, and OF will be very nearly equal in length to PF. Since OF = FC, this would mean that PF will be very nearly equal to FC, or, in other words, that F will be very nearly the mid-point of PC. The closer IO is to PC, the closer is F to the mid-point of PC. Thus a beam of rays all parallel to the principal axis and very near it, would, after reflection, all pass through the mid-point (or very nearly so) of the line joining the pole of the mirror to its centre of curvature. This is shown in Fig. 12.20(a). The point through which all these rays pass after reflection is known as the principal focus of the concave mirror. Similarly Figs. 12.19(b) and 12.20(b) show the principal focus of a convex mirror to be the point midway between the pole and the centre of curvature from which rays, all parallel to the principal axis and very near it, appear to diverge. Thus a ray of light parallel to the principal axis and very near it, would, after reflection from a concave mirror, pass through its focus, and would, after reflection from a convex mirror appear to be coming from its focus. The principle of reversibility tells us therefore that any ray through the focus would, after reflection, move parallel to the principal axis of the mirror. The distance from the focus to the pole is known as the *focal length* of the mirror.

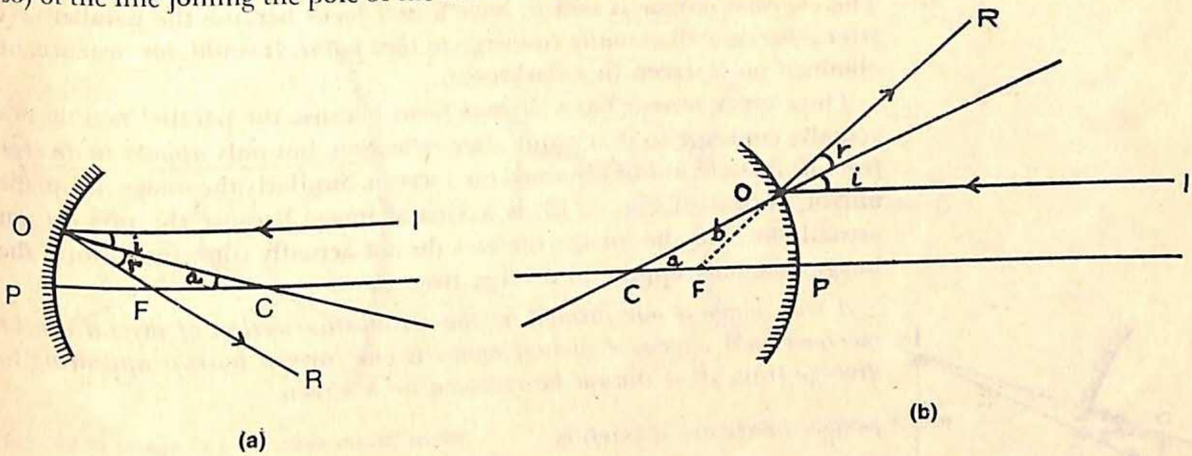


Fig. 12.19 **How a ray of light is reflected from (a) a concave mirror (b) a convex mirror**

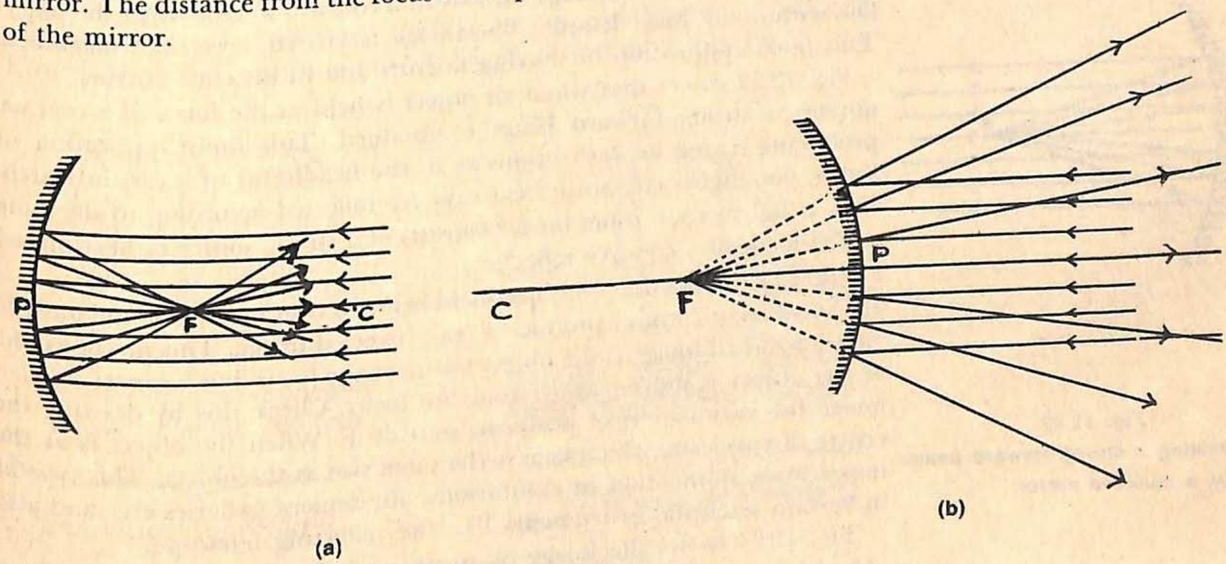


Fig. 12.20 **(a) Focus of a concave mirror (b) Focus of a convex mirror**

Real and Virtual

The *concave mirror* is said to have a *real focus* because the parallel *rays* after reflection all *actually converge to that point*. It could, for instance, be obtained on a screen in a darkroom.

The *convex mirror has a virtual focus* because the parallel *rays* do not actually converge to that point after reflection, but only *appear to diverge from it*; it could not be obtained on a screen. Similarly the image in a plane mirror, shown in Fig. 12.13, is a virtual image because the rays do not actually meet at the image; the rays do not actually converge to form the image, but only appear to diverge from it.

A real image is one formed by the actual intersection of rays; it can be received on a screen. A virtual image is one formed by rays appearing to diverge from it; it cannot be received on a screen.

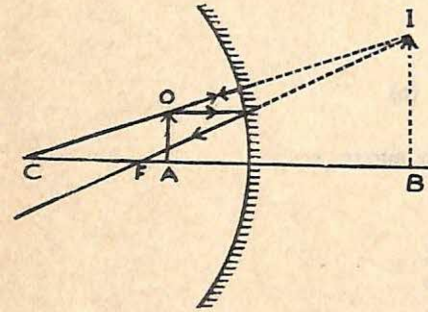


Fig. 12.21 **Image in a concave mirror when the object is within the focal length**

Images in Spherical mirrors

To construct the image point of any object point, draw the following rays:

1. The ray from the object point parallel to the principal axis which, after reflection, passes through the principal focus.

2. The ray through the centre of curvature which, since it strikes the mirror normally, or perpendicularly, will, after reflection, return along the same path.

3. The ray through the principal focus which, as we have seen from the principle of reversibility, would, after reflection, move parallel to the principal axis.

Generally the first two rays are enough; the third is only required when the second is not possible, e.g. when the object is at the centre of curvature.

Fig. 12.21 shows the image formed in a concave mirror when the object lies within the focal length. The image is virtual, erect and magnified. This finds application in shaving mirrors and in dentist's mirrors.

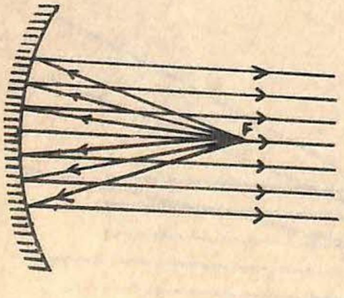


Fig. 12.22 **Obtaining a strong forward beam from a concave mirror**

Fig. 12.22 shows that when an object is held at the focus of a concave mirror, a strong forward beam is obtained. This finds application in producing strong forward beams as in the headlights of a car, in searchlights, floodlights etc. Since heat rays are reflected according to the same laws as light rays, a room heater consists of a strong source of heat placed at the focus of a concave reflector.

Fig. 12.23 shows that an object held before a concave mirror and outside the focal length would produce a real, inverted image. This image would be a magnified image if the object was near the focus, but becomes smaller as the object is moved away from the focus. Check this by drawing the image for various object positions outside F. When the object is at the centre of curvature, the image is the same size as the object. This type of image finds application in exhibitions, amusement galleries etc., and also in certain scientific instruments like the reflecting telescope.

Fig. 12.24 shows the image of an object held before a convex mirror. The image is always virtual, erect and diminished in size. This is why the rear-view (driving) mirrors in cars and motor cycles are convex mirrors. Since the image is diminished a wider area of view of the traffic behind is obtained.

At this stage it is useful to remember that the image in a plane mirror is virtual, erect, and of the same size as the object.

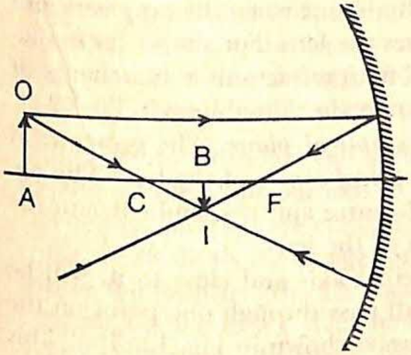


Fig. 12.23 **Image in a concave mirror when the object is outside the focal length**

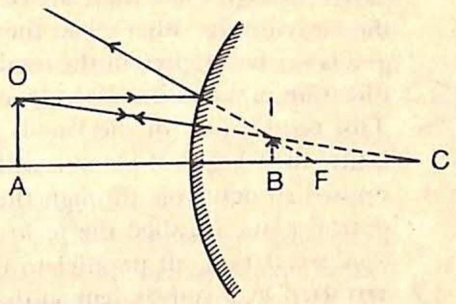


Fig. 12.24 **Image in a convex mirror**

Concave and convex mirrors which are not spherical will produce similar images. Look into the curve of a shiny metal spoon first held close and then held further away. Then turn the spoon around and look into its convex face.

5. Lenses

A *lens* is a piece of transparent refracting medium, usually glass, bounded either by two curved surfaces or by one plane and one curved surface. The word 'lens' is the Latin word for 'lentil', and the name was given first to convex lenses because of their similarity in shape to lentil seeds, which in India we call 'dal'.

Lenses are called convex if they are thicker at the middle than at the ends, and concave if they are thinner in the middle than at the ends. Lenses are named according to their shape, as shown in Fig. 12.25.

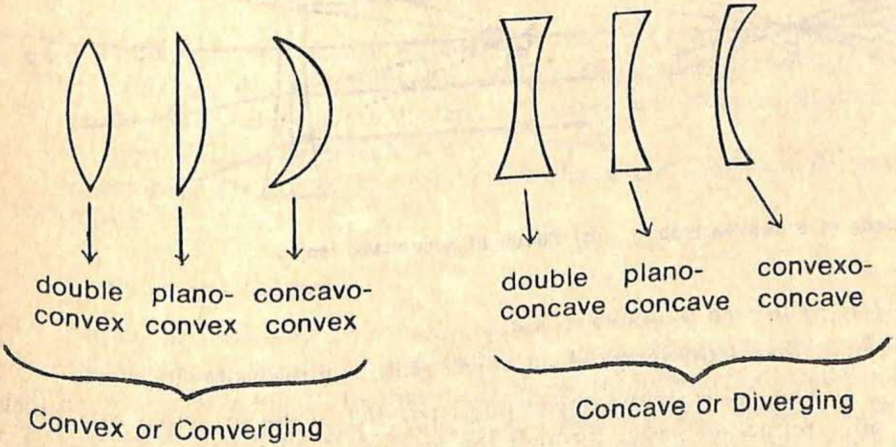


Fig. 12.25 **Different types of lenses**

It is helpful (see Fig. 12.26) to consider a double convex lens as two triangular prisms base to base, and a double concave lens as two prisms apex to apex, and to apply our knowledge of the refraction through a triangular prism shown in Fig. 12.16. We see that *a convex lens converges light, while a concave lens diverges light.* Note that when a ray of light passes through a lens there are two refractions; one when the ray passes into the lens and the other when the ray leaves the lens. For simplicity in diagrams we shall represent the total effect of both refractions as one change of direction in the centre of the lens, as shown by the dotted lines in Fig. 12.26. This central part of the lens is called its *optical plane*. The geometrical centre of the optical plane is called the *optical centre* of the lens. The unlimited straight line through the optical centre and perpendicular to the optical plane is called the *principal axis* of the lens.

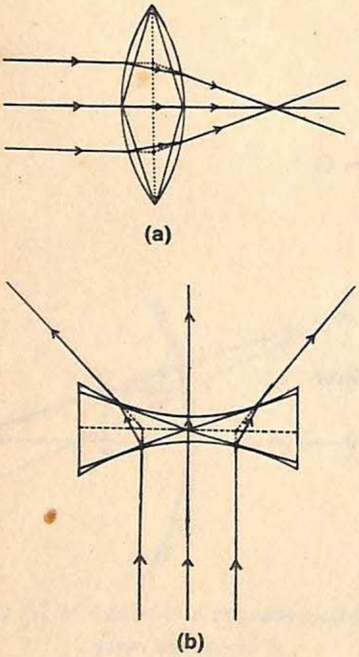


Fig. 12.26

How light is refracted

(a) through a convex lens

(b) through a concave lens

A set of rays, all parallel to the principal axis and close to it, will be refracted by a convex lens so that they all pass through one point on the principal axis on the other side of the lens as shown in Fig. 12.27(a). This point is called the *principal focus* of the lens. The distance of the principal focus from the optical centre of the lens is called the *focal length* of the lens. A set of parallel rays which strike the other face of the lens would be converged to a corresponding point on the other side of the lens. A convex lens therefore has two principal foci, symmetrically placed on each side of the lens. Fig. 12.27(b) shows how a concave lens would refract such a parallel beam. The rays after passing through the lens all appear to diverge from one point on the principal axis on the same side of the lens. This is the principal focus of the concave lens; its distance from the optical centre is called the focal length of the lens. The other principal focus is symmetrically placed on the other side of the lens, just as in the case of the convex lens. Thus a convex lens has two real foci, but a concave lens has two virtual foci. The plane through the focus of a lens perpendicular to the principal axis of the lens is called the *focal plane* of the lens.

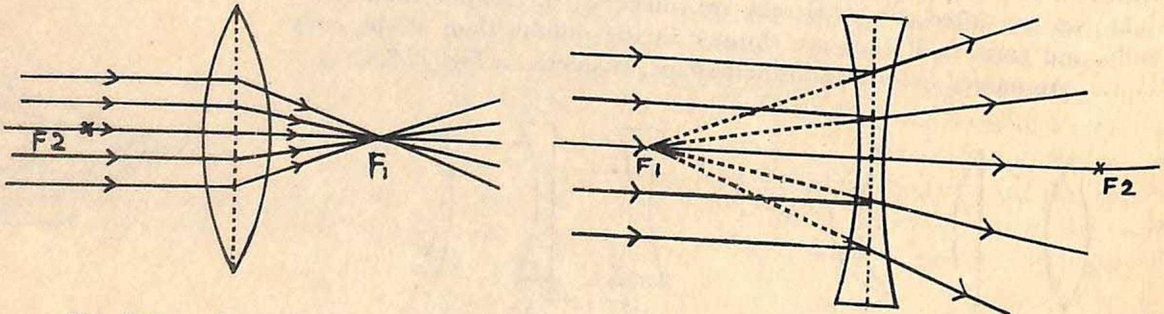


Fig. 12.27 **(a) Focus of a convex lens** **(b) Focus of a concave lens**

Images formed by lenses

To construct the image of an object point use the following rays:

1. The ray from the object point parallel to the principal axis which after refraction passes through the first principal focus in the case of a convex lens, or appears to be coming away from the first principal focus in the case of a concave lens.

2. The ray through the optical centre which goes on in the same direc-

tion, because it passes through the centre of the lens where the two opposite surfaces are parallel. The situation is similar to a ray being refracted through a parallel-sided glass block. As shown in Fig. 12.15, the ray emerges parallel to itself but suffers a sideways shift. If the glass block is not very thick, and if the ray is not very oblique, this shift is negligible Hence a ray passing through the optical centre of a thin lens, and striking it almost perpendicularly is considered to go on in the same direction.

3. The ray through the second focus which after refraction moves parallel to the principal axis.

The first two rays are enough to construct the image.

Fig. 12.28 shows the image formed by a convex lens when the object is within the focal length. The image is virtual, erect and magnified, which explains the use of a convex lens as a *magnifying glass.*

Fig. 12.29 shows the image formed by a convex lens when the object is outside the focal length. The image is real and inverted. This is the type of image formed by a projecting lantern or slide projector, by a camera, and by the human eye. By drawing ray diagrams find out what happens to the size of this image as the object is moved further away from the lens, starting from a position just outside the focus.

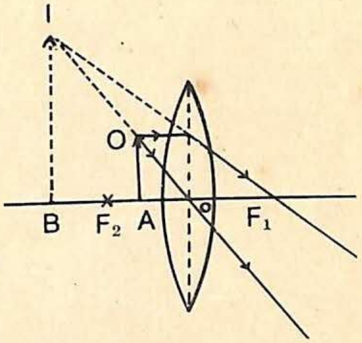


Fig. 12.28 **Image in a convex lens when the object is within the focal length**

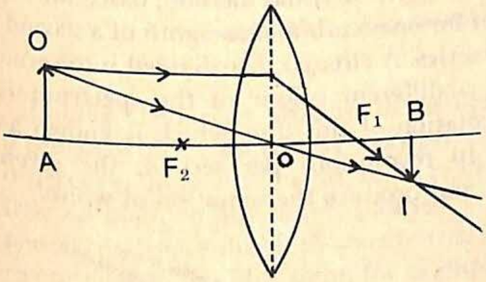


Fig. 12.29 **Image in a convex lens when the object is outside the focal length**

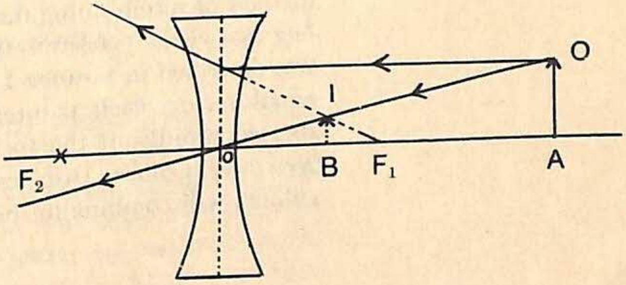


Fig. 12.30 **Image in a concave lens**

Fig. 12.30 shows the image formed by a concave lens. The image is virtual, erect and diminished in size. Will the image change in nature as the distance of the object from the lens is changed, and, more particularly, if the object is inside or outside the focal length?

In each of the Figs. 12.28, 12.29 and 12.30 what would happen if IB were the object?

6. Dispersion and Colour

Dispersion. In 1666 Newton caused a beam of sunlight, passing through a circular hole in a window blind, to fall on a triangular glass prism. He found, as we saw in Fig. 12.16, that the light was refracted or deviated from its original path, but instead of obtaining a simple image of the hole, he obtained a band of colours, which he called a *spectrum*. Its colours were the same as those found in a rainbow – red, orange, yellow, green, blue, indigo and violet, with each colour merging into the next. Newton reasoned that white light must be *composite*, that is made up of a combination of the above colours. The separation of the colours by the prism he called *dispersion*. Fig. 12.31 shows the dispersion of white light into its spectrum by a prism. This dispersion occurs because the different colours are bent or refracted through different angles by the prism, red being deviated the least, violet the most, and the intermediate colours being bent through angles gradually increasing from red to violet.

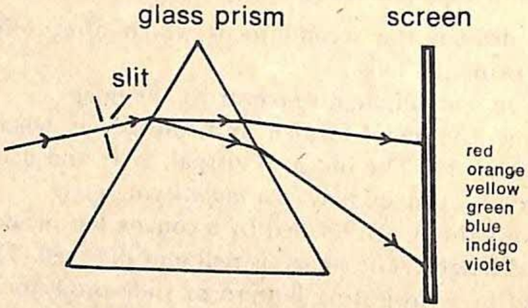


Fig. 12.31 **Dispersion**

Fig. 12.32 shows how a second prism held in the reverse position to the first will recombine the seven colours into white light. This is an optical method of recombining the dispersed light. A visual method, based on the fact that vision persists in the brain for one-tenth to one-eighth of a second, was described in Volume I of this series. A circular disc divided into seven equal sectors each painted with a different colour of the spectrum is rotated rapidly. If the speed of rotation of this disc, which is known as Newton's Colour Disc, exceeds 10 revolutions per second, the seven colours will combine in the brain and produce the sensation of white.

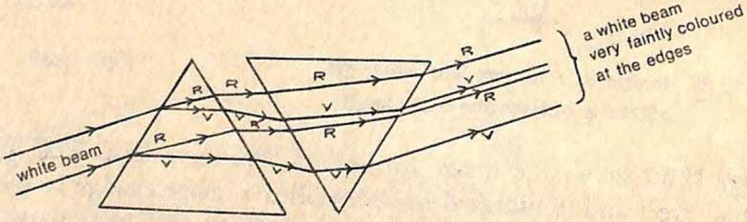


Fig. 12.32 **Recombination of dispersed light with another prism**

The spectrum produced in Fig. 12.31 is impure because of considerable overlapping of the colours. Fig. 12.33 shows how a pure spectrum can be obtained. A beam of light from a ray box is directed on to a slit. A convex lens is placed in the light diverging from the slit, and these rays are focussed on the screen at A. A prism is now placed in the path of the beam. If this prism is rotated, the emergent beam sweeps to and fro. The position of the prism is adjusted until the emergent beam is as near as possible to A. The prism is now in the position where it produces minimum deviation. The screen is now moved into the path of the beam, and its position is adjusted until the light that falls on it is in clear focus. A pure spectrum is now obtained on the screen. It consists of an infinite series of coloured images of the slit focussed side by side on the screen.

Newton picked out what he considered to be the most prominent colours in the spectrum, violet, blue, green, yellow, orange, red (VBGYOR). Newton included indigo, between the violet and the blue, but most people cannot distinguish it. What must be understood, however, is that there are really an infinite number of colours in the spectrum, just as there are an infinite number of points in a line of given length. We have only a limited number of names for colours, and the word 'red', for example, has to cover a wide range of tints.

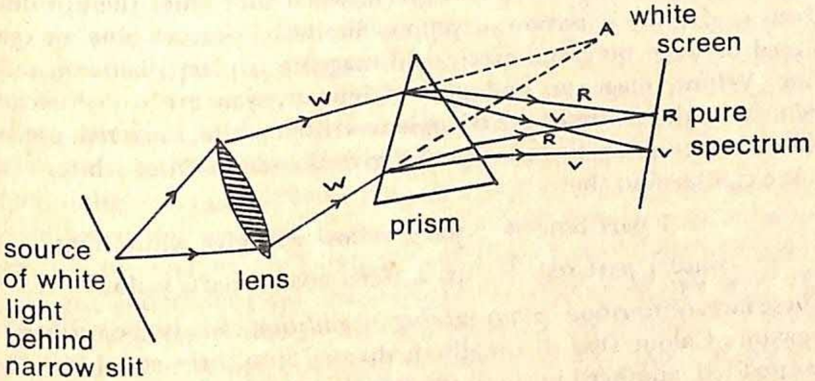


Fig. 12.33 **How to obtain a pure spectrum**

Colour. Colour is a property of the light which reaches our eyes; it is not a property of the objects we see since the same object can appear to have different colours. A red cloth looks red in white light and in red light, but it looks black in any other coloured light. This is because the colouring matter, or dye, of the cloth absorbs every other colour and only reflects red to our eyes. When blue light, for example, falls on it the red cloth will not reflect any light to the eye, since there is no red light for it to reflect. Similarly a blue cloth absorbs every colour except blue, which it reflects to our eyes. A blue cloth illuminated in white light will absorb all the other colours from the white light that falls on it, and will only reflect blue light to our eyes. If no blue light falls on it, no light will be reflected by it to our eyes, and so it will look black. A white object is able to reflect every colour. In white light it looks white because it reflects all the colours that make up white to our eyes. In red light it looks red because it is able to reflect red light to our eyes, and in blue light it looks blue because it reflects blue light to our eyes. A black object absorbs every colour and does not reflect any light to our eyes and that is why it looks black; black results from the absence of all colours.

Colour mixing. Some very instructive experiments can be performed using the ray box described in Fig. 12.7, with plates of different colours which will produce beams of different colours. A red plate, for example, will absorb every colour from white light except red, and will only transmit a red beam through the slit. Direct a red beam, a blue beam and a green beam on to a white screen. The colours combine to produce white. Red light and green light directed on to a screen would overlap to produce yellow; blue light shone on to this yellow patch will make it white. Blue

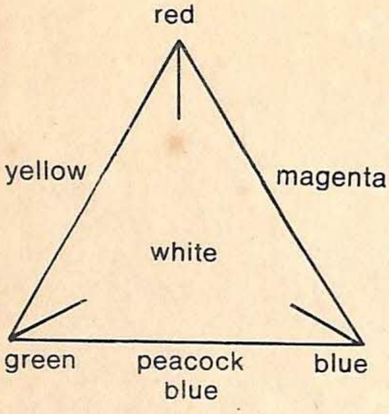


Fig. 12.34 **The colour triangle**

light mixed with green light produces a colour called peacock-blue or cyan. What light must be shone on to this cyan patch to make it white? Red added to blue produces a colour called magenta. Two colours which together produce white are called *complementary colours*. Thus blue and yellow are complementary colours. What is the complementary colour to magenta? A useful aid to memory is the colour triangle shown in Fig. 12.34. The three colours, red, green and blue, known as the *primary colours* are placed at the vertices of an equilateral triangle. Midway between red and green is yellow because red and green, when they enter the eye simultaneously, give the sensation of yellow. Similarly, peacock-blue, or cyan, is placed between blue and green, and magenta is placed between red and blue. Yellow, magenta, and peacock-bue or cyan are called *secondary colours*. At the centre of the triangle is written white, since red, green and blue when entering the eye together give the sensation of white.

We can see also that:

1 part blue + 2 parts yellow will give white light
since 1 part red + 1 part green gives 2 parts yellow.

These facts concerning *colour mixing by addition* can also be verified using Newton's Colour Disc. If the disc is divided into three equal sectors, one painted red, another blue, and the third green, the disc will appear white when rotated sufficiently rapidly. If of the three sectors, one was painted blue and the other two yellow, the disc would look white when rapidly rotated.

If the disc is divided into two sectors, one red and one green, and rotated sufficiently rapidly it will appear yellow. If a complete colour disc, i.e. one with seven equal sectors coloured red, orange, yellow, green, blue, indigo, violet, had the green sector cut out, the remaining part of the disc would look magenta if rapidly rotated. This is because green plus magenta gives white, and so white minus green will give magenta.

However all that we have said presumes that the disc is coloured with spectrally pure colours and is illuminated by white light. In practice however these colours are never absolutely pure, and you will not get perfect results.

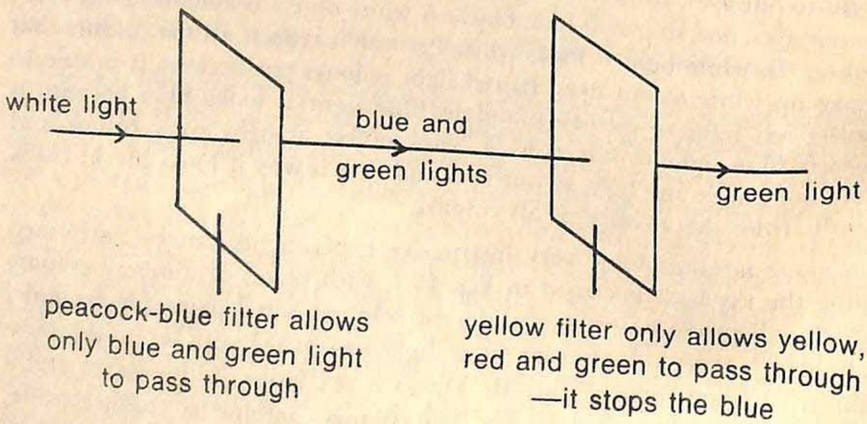

white light
blue and
green lights
green light
peacock-blue filter allows only blue and green light to pass through
yellow filter only allows yellow, red and green to pass through —it stops the blue

Fig. 12.35 **A peacock-blue filter and a yellow filter together transmit green**

Let us now attempt some *colour mixing by subtraction*. A piece of red glass held in the path of white light will absorb all the other colours and only allow red light to pass through it; for this reason it is called a red filter. It should be clear that a red filter and a blue filter held together in the path of white light would not let any light through and the combination looks black. Fig. 12.35 shows a peacock-blue filter and a yellow filter held in the path of white light. The peacock-blue filter, as the name implies, filters all colours out of the incident light except blue and green. The yellow filter permits only yellow, red and green light to pass through it, and so the only colour which is transmitted by both is green. A similar effect is achieved by putting a layer of blue paint over a layer of yellow paint on a sheet of white paper. Paints or pigments are never spectrally pure; their colour is always contaminated with those colours that are adjacent in the spectrum. Thus blue paint will be contaminated with some violet (and indigo) and green, while the yellow paint will be contaminated with some green and orange. The layer of blue paint acts as a filter allowing only blue, violet (and indigo) and green light to pass through. The blue light and violet (and indigo) light are stopped by the layer of yellow paint which will only allow yellow, green and orange to pass through. Thus the only light that can pass through both layers is green. This green light is reflected off the white paper below, and when it reaches the eye it gives the sensation of green. Thus we have the answer to the anomaly: blue light mixed with yellow light gives white, but blue paint mixed with yellow paint gives green. The former is colour-mixing by addition; the latter is colour mixing by subtraction. Draw a diagram similar to Fig. 12.35 to represent what happens in the case of mixing blue and yellow paints. Why is the green produced a weak green, and not as strong as the green from green paint? Mix together copper sulphate solution and potassium dichromate solution: what is the resulting colour? Why? What will be the colour transmitted by peacock-blue, yellow and magenta filters held together? Why?

Using a filter in front of a ray box, illuminate specimens of coloured paper or wool with coloured light, or examine coloured specimens in daylight through coloured filters. In this case the pigment of the paper or wool will reflect only certain colours in the incident light. For example, peacock-blue light falling on a yellow paper will make it appear green, for the paper will reflect yellow, red, green and orange light, but the yellow, red and orange are absent in the peacock-blue light and so only green is reflected. What colour will a yellow cloth appear to have in magenta light?

Many amazing effects are produced on a theatre stage by simple applications of the principles we have been studying. A masked figure appearing in red against a black background can be made to disappear almost completely if the lights shining on the figure are switched from white to green. Can you explain why? A yellow costume, as we saw above, will change to red if magenta light falls on it, and to green if peacock-blue light falls on it.

White fabrics acquire a yellowish colour after repeated washings. A bluish dye added during washing neutralizes the yellowish colour and the fabrics appear white. Is this colour mixing by addition or by subtraction?

An ordinary electric light-bulb emits light in which there is a greater proportion of red and yellow, and a lower proportion of blue, than in sunlight. It is therefore impossible to match colours in artificial lighting. Many stores provide powerful 'daylight' lamps for this purpose. These lamps are tinted blue to cut down the proportion of red and yellow light, and to give out light of a composition similar to daylight. Another type of daylight lamp has a reflector painted a blue-green colour.

Colour Vision. How the eye detects colour, or how it fails to as in the case of colour blindness, is fully explained in Chapter 4, section 4. Read this section again carefully, in the light of all that has been said above.

Questions

1 Draw a diagram to explain the formation of the shadow of an opaque object held before a large source of light. Use this diagram to explain why the shadow of an opaque object held before a large source appears blurred around the edges, and why this blurring increases in width as the distance between the body and the screen is increased.

2 Draw a ray diagram, one in each case, to explain the formation of (a) a lunar eclipse, (b) a solar eclipse, (c) an annular eclipse, and explain:

(i) what is meant by the 'track' of a solar eclipse;

(ii) why a lunar eclipse can be witnessed all over the world, but a solar eclipse is only experienced by those on a certain part of the earth's surface;

(iii) how a lunar eclipse provides evidence that our earth is round in shape;

(iv) when it is a partial eclipse, and when it is a total eclipse, in the case of both solar and lunar eclipses;

(v) why a total eclipse of the sun observed from any one place on the earth's surface, lasts a much shorter time than a total eclipse of the moon?

3 Explain the formation of the numerous bright circular patches of light seen on the ground under a leafy tree.

4 State the laws of reflection of light, and explain how you would verify them given a drawing board, drawing paper, pins and a plane mirror.

5 How would you locate the position of the image experimentally? State this position.

6 What is 'lateral inversion' and why does it occur? Give two different examples of lateral inversion.

7 Draw a ray diagram to explain the formation of the image of an object in a plane mirror. State *six* facts about this image.

8 Draw the arrangement of mirrors that would enable a man to see over a high wall. Trace the rays from the object to his eye.

(*Note*—If you have forgotten the action of a periscope, read p. 58 of Volume I again).

9 Sketch an arrangement of two mirrors which would enable a man to see the top of his own head. Trace the path of the rays.

10 What is meant by the 'refraction' of light? Draw ray diagrams to show the refraction of a ray of light when it passes (a) from a rarer to a denser medium, (b) from a denser to a rarer medium.

11 Draw ray diagrams to show how a ray of light which strikes one face obliquely is refracted through a parallel-sided glass block. Draw a ray diagram to show how the ray would have been refracted through the block if it had struck the first face perpendicularly. How would you verify both these cases by experiment?

12 Explain with the help of ray diagrams why an object appears to be raised by refraction (a) when the object is being looked at from vertically above, (b) when the object is being looked at sideways from above.

Mention one example of each case from everyday life.

13 Given either a ray box, or pins and drawing paper, explain how you would proceed to investigate by experiment how a ray of light is refracted through a triangular glass prism.

Draw a diagram to show the result you would obtain. Mark on your diagram the angle through which the prism turns the ray.

14 Draw a ray diagram, one in each case, to show the formation of (a) a virtual image (b) a real image, in a concave mirror. Explain one use to which the first image may be put.

15 Draw a ray diagram to show the image formed in a convex mirror. Is this image real or virtual? Why is a convex mirror preferred to a plane mirror for use as the rear-view mirror in a car or motor cycle?

16 Explain with a ray diagram how a concave mirror can be used to obtain a strong forward beam. State two applications of this.

17 Which lens, convex or concave, (a) is converging, (b) is diverging, (c) has a real focus, (d) has a virtual focus?

18 Draw a ray diagram, one in each case, to show the formation of (a) a real image, (b) a virtual image, in a convex lens.

Describe one practical application of each image.

19 Draw a ray diagram to show the formation of an image in a concave lens. Describe the nature and size of the image.

20 Draw a ray diagram to show how a convex lens can be used as a 'burning glass'.

21 Explain, with a ray diagram, how you would obtain a pure spectrum on a screen. Describe the appearance of the spectrum.

A spectrum has been described as a colour analysis of white light. Explain how the prism analyses, or breaks up, the white light into its constituent colours. How many colours are there in the spectrum? How many colours are easily identifiable?

22 Explain, with a ray diagram, an optical method of recombining the light dispersed by a prism.

Describe a visual method of recombining the dispersed light.

23 Describe and explain the appearance of a red rose with a green leaf (a) in white light, (b) in red light, (c) in green light, (d) in blue light, (e) in yellow light, (f) in magenta light, (g) in peacock-blue (or cyan) light.

24 What is meant by (a) primary colours, (b) secondary colours, (c) complementary colours? Name the primary and secondary colours, and give two examples of complementary colours. Draw and explain the 'colour triangle'.

25 Blue and yellow lights when mixed produce white, but blue and yellow paints when mixed produce green. Explain why. Name another pair of coloured lights which when mixed produce white, and name the colour that would be produced when pigments of these colours are mixed.

Describe and explain two methods by which you would demonstrate experimentally that blue light and yellow light when mixed produce white.

Why is blue colouring matter often added to the water in which white clothes are washed?

26 A peacock-blue filter and a yellow filter are placed together in the path of white light. What colour light do they transmit? Why? A magenta filter is now held together with them in the path of white light. Describe and explain the result.

27 White chalk is sometimes difficult to see on a blackboard when one is seated in certain positions in a classroom. Explain this, illustrating your explanation with a diagram of a plan of some classroom with which you are familiar. State, giving a reason, whether yellow chalk would be better than white in this connection.

28 Explain why it is impossible to match colours in artificial light. What help do large stores and shops provide in this respect? Explain why purple cloth appears red by lamplight. Which colours would be the most difficult to match in artificial lighting?

13
More About Sound

1. The production and transmission of sound

In this section we are going to talk about what starts a sound and how it gets to the ear. Since much of this has been said in Chapter 4, section 2, it will be most helpful if you study that section again carefully before we go any further.

What starts a sound is the vibration of the sounding body. This vibration produces areas of alternate high and low pressures, or compressions and rarefactions as they are called, in the air surrounding the body. We shall now study in greater detail how these are produced.

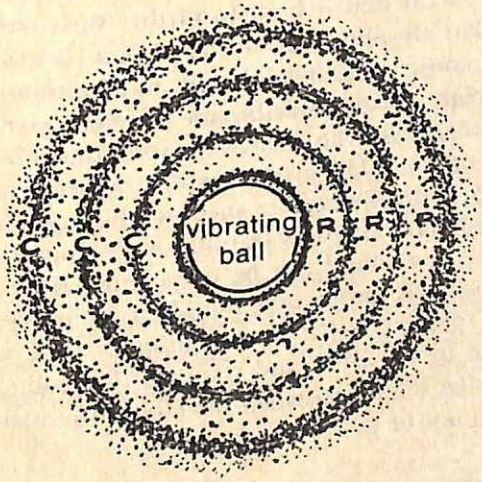


Fig. 13.1 The mechanism of sound transmission

Let us suppose that we have an elastic ball (see Fig. 13.1) for a source of sound, and that by some means the ball is made to expand and contract regularly; that is each point on the surface of the ball is made to move back and forth, outward and inward, along a radius of the ball. As the ball expands it pushes the air outward, crowding the air molecules closer together so it produces a spherical region at its surface where the density and pressure of the air are slightly greater than normal. This region is called a *compression* or a *condensation*.

A moment later the ball contracts, leaving at its surface a spherical region where the density and pressure of the air are slightly less than normal. This region is called a *rarefaction*. The molecules that formed the compression crowd against the molecules beyond them and then move back into the rarefaction next to the surface of the ball, where they are again in a position to get pushed outwards by the next expansion of the ball. Thus the movement of molecules at the surface of the ball is passed on to the molecules farther out, although the molecules themselves only vibrate back and forth, toward and away, from the vibrating body which is the source of the sound. The alternate compressions and rarefactions so produced follow each other in rapid succession through the air. This sets up a mechanical disturbance in the air. When this disturbance, called a *sound wave*, reaches the ear, the sensation it produces in the ear is received by the brain as the sensation of hearing. The process of hearing is described in Chapter 4.

It must be stressed that sound cannot travel through a vacuum. This was demonstrated experimentally in Fig. 4.11. There must be some matter between the sounding body and the ear to transmit the alternate compressions and rarefactions, some material medium to carry the sound wave. This material medium is usually air, but it can be any solid, liquid or gas. Now we have formed a picture of how alternate compressions and rarefactions are formed and how they travel through the air. This picture presents no difficulty as far as liquids and gases are concerned, but our imaginations might find it hard to picture such waves in solids. We must remember that all solids are elastic and that their molecules are free to vibrate. To demonstrate that solids can, and do, transmit waves of this sort, place six or eight marbles side by side between two metre sticks. Now roll another marble along the groove between the two sticks so that it strikes one end of the row. The marbles in the row are not visibly disturbed except for the one at the other end of the row which gets moved away some distance, showing that energy was transmitted by the marbles.

Evidence proves that sound can be transmitted through matter in all states. In fact it can be shown that liquids transmit sounds better than gases, and that solids are the best transmitters of all. Perform the experiment shown in Fig. 13.2, and compare the loudness of the sounds produced by striking the spoon when the end of the string is held first in your ear and then out of your ear.

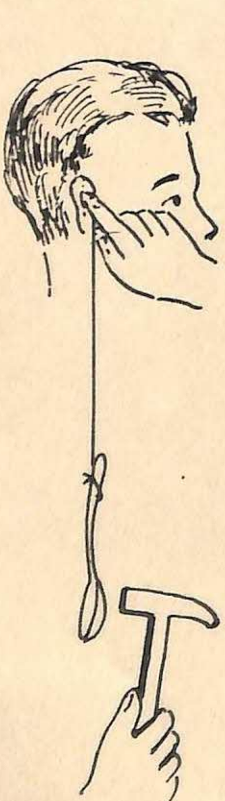


Fig. 13.2

Sound travels through a string

2. The Velocity of sound in air

The most direct way to measure the velocity of sound in air is shown in Fig. 13.3. An observer at A causes an explosion by igniting gunpowder so that a flash as well as a bang are produced. An observer at B, a known distance e.g. 2 kilometres from A, watches for the flash. When he sees it he starts a stop-watch. When the bang reaches him he stops the stop-watch. Since the velocity of light is very great, 300 000 kilometres per second, we consider the time the flash takes to travel from A to B to be negligible. The time recorded by the stop-watch is therefore the time taken by the sound to travel from A to B. If the distance between A and B is divided by this time, we get a value for the velocity of sound in air. To eliminate any wind effect a reciprocal observation is taken i.e. the explosion is now produced at B and the timing by the stop-watch is done at A. The value of the velocity of sound from B to A is calculated; the average of this value and the value calculated before gives a more accurate result for the velocity of sound in air. This method, in various forms, gave the first information

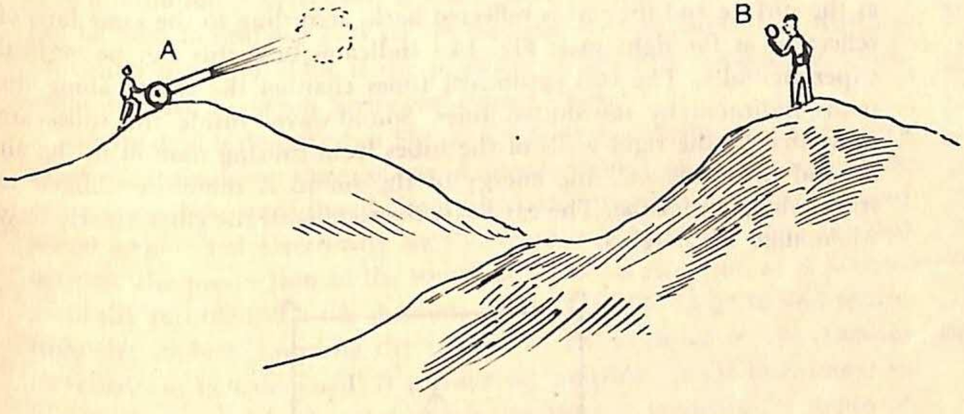


Fig. 13.3 **Open air determination of the velocity of sound**

about the velocity of sound in air. It is not accurate because of what is termed the 'personal error' of the operator. No human operator can start and stop the stop-watch at exactly the precise moment required. Eyes and ears signal to the brain; nerves and muscles take time to react and operate. This delay, which is called the 'reaction time' of the operator, varies from one individual to another. Various electrical methods have been used to record the time of the flash and the bang, to obtain a more accurate value for the velocity of sound in air, by eliminating the personal error of the operator, and we shall study these, and other accurate methods, in Volume 3 of this series. Very accurate measurements show that at 0°C, in free air, the velocity of sound is 331.5 metres per second. Sound travels faster in warmer air, the velocity increasing by about 0.6 m/sec for every 1°C rise in temperature. Thus at 20°C the velocity of sound in dry still air will be

$$\begin{aligned} 331.5 + (0.6 \times 20) &= 331.5 + 12 \\ &= 343.5 \text{ m/sec.} \end{aligned}$$

If you want to estimate how far away a lightning flash occurred, time the interval between the lightning flash and the sound of the thunder and multiply this number of seconds by 340. The result will give you an approximate value for the distance in metres of the lightning flash from you.

The speed of sound in water is about four times that in air; in water at 0°C sound travels at 1 440 m/sec. The velocity of sound in sea-water is 1 540 m/sec. In steel, sound travels at 5 000 m/sec, almost fifteen times as fast as in air, while the velocity of sound in brass has been calculated to be about 3 650 m/sec.

3. Reflection of sound

Find a hard smooth-surfaced wall in your school building. Stand about twenty metres away from it and clap your hands sharply. You will hear an answering clap shortly after your own. This is the *echo*; the word comes from the Greek word for 'sound'.

Whenever a sound strikes a solid surface, part of the sound is absorbed at the surface and the rest is reflected back, according to the same laws of reflection as for light rays. Fig. 13.4 indicates how this can be verified experimentally. The two cardboard tubes channel the sound along the paths indicated by the dotted lines. Sound-waves inside the tubes are prevented by the rigid walls of the tubes from causing motion in the air around the tubes. All the energy of the sound is therefore obliged to travel along each tube. The ear hears the ticking of the clock clearly only when angle r = angle i.

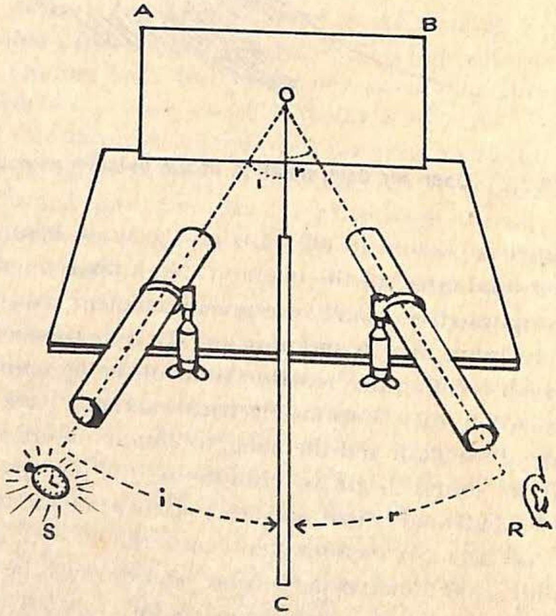


Fig. 13.4 **Reflection of sound**

When the reflected sound is heard it is called an echo. An echo is always much weaker than the original sound, because the original sound has spread out to cover a very large sound sphere before it reaches the wall, and the reflected wave spreads out again in a similar way on the way back. The fact that we are able to hear echoes tells us how very sensitive the human ear is. Note that the function of the cardboard tubes in Fig. 13.4 was to prevent such spreading out.

We have mentioned in Chapter 4 and again in Chapter 12 that sensations linger in the brain for a period of approximately one-tenth of a second. In this time sound travels about 34 metres. Thus if you were closer than 17 metres to the reflecting surface you would not hear the echo of your hand clap, because the reflected sound would take less than one-tenth of a second to travel to the surface and back. Thus the reflected sound is heard while the sensation of the original sound still lingers in the brain, and cannot be distinguished from it. To hear the echo of your handclap you will need to be at a greater distance from the reflecting surface, e.g. the large smooth wall we spoke of at the beginning of this section, than the distance sound travels through the air in 1/20 sec.

Depth-sounding by echoes. If the velocity of sound is known an echo can be used to find out how far the observer is from the surface which is providing the echo. This is the principle of the echo method of depth-sounding used by ocean liners and fishing ships.

The method is described in Fig. 13.5. S is an electrically operated source of sound; it sends out sharp pulses of sounds which pass down through the water to the bottom of the sea from which they are reflected. The reflected sound is detected electrically by the receiver R, and the time interval between the production of the sound at S and its reception at R is automatically recorded. This is the time taken by sound to go to and return from the sea-bed. Knowing the velocity of sound in water, the distance travelled can be calculated. It is therefore possible for the instrument to plot these times directly on a graph marked out in metres of depth of water below the ship. The instrument is called a 'Fathometer'.

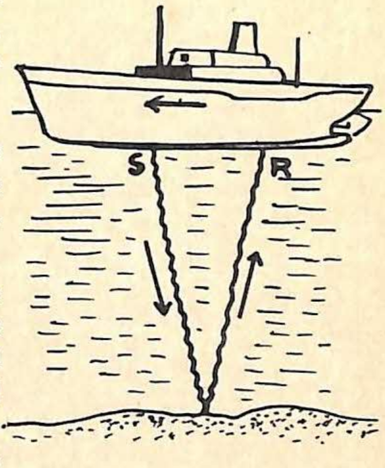


Fig. 13.5 **Depth — sounding**

4. Pitch and loudness

The *pitch* of a sound refers to how high or low pitched the sound is. Thus a child's voice and a woman's voice are high-pitched while a man's voice is low-pitched. The notes on the left of a piano keyboard are low-pitched while those on the right are high-pitched. In Section 2 of Chapter 4 we learned that *the pitch of a sound depends on the frequency* i.e. the number of complete vibrations per second made by *the sounding body*. The higher the frequency, the higher the pitch; the lower the frequency, the lower the pitch. This is clearly established by the experiments described in Fig. 4.13.

Sounds of the same frequency or pitch can differ in their *loudness*. Strike a piano key gently and then strike the same key harder; the sounds heard are of the same pitch but the second sound is louder than the first. Why? To find the answer you will have to remove the wooden cover and watch the vibration of the string in question as that particular key is struck. A harder impact on the key causes the metal piano wire, or 'string', to vibrate through a greater distance. The distance between the two extreme positions of the vibrating body is called the *amplitude* of the vibration.

Press a metre stick against a table top as shown in Fig. 4.14. Strike the end that projects over the table top, first gently and then harder. How did the amplitude of the vibration change? How did the loudness of the sound change?

These experiments show us that *the loudness of a sound increases or decreases with the amplitude of the vibration of the sounding body:* How many other experiments can you think of to support this statement?

Questions

1 Describe the transmission of a sound through the air from the sounding body to the listener's ear.

2 Describe a simple method to determine the velocity of sound in air. Why is a 'reciprocal observation' necessary? What is meant by 'personal error', and what methods are employed to eliminate this error from the method you have described.

How would the result obtained for the velocity of sound in air on a cold day differ from that obtained on a hot day?

3 Your ear is placed against the metal rail of a railway track. At some distance from you the rail is struck with a hammer. If you are quick enough you can hear two sounds. Explain how and why.

4 How would you show by experiment that when sound is reflected from a surface the angle of incidence is equal to the angle of reflection? Draw a diagram of the arrangement of apparatus you would use.

5 Explain how the depth of water below a ship is measured.

6 Explain why you hear a sound more loudly when a cardboard tube connects the sounding body to your ear.

Why is an echo much more faint than the original sound?

Why is it that the teacher's voice sounds louder in a classroom than in the open air.

7 Explain the difference in sound heard when you speak in a heavily curtained room full of people and when you speak in an empty room with bare plaster walls.

8 Why is there a minimum distance from the reflector for an echo to be distinguished? What is this minimum distance on a day when there is no wind and the temperature is 10°C?

9 What is meant by the 'amplitude' of vibration of a sounding body? Describe an experiment to show that the loudness of a sound depends upon the amplitude of vibration.

10 Ask yourself the following questions about light and sound: Are both energy? Are both reflected according to the same laws? How do their speeds compare? Can both travel through vacuum?

Now state two points of similarity and two points of difference between light and sound.

14

More About Magnetism

CHAPTER 6 introduced you to the study of Magnetism, and at this stage you should go over that chapter again and make sure that you have understood the basic facts explained there. In this chapter we shall learn some more about this part of Physics.

1. Magnetic induction

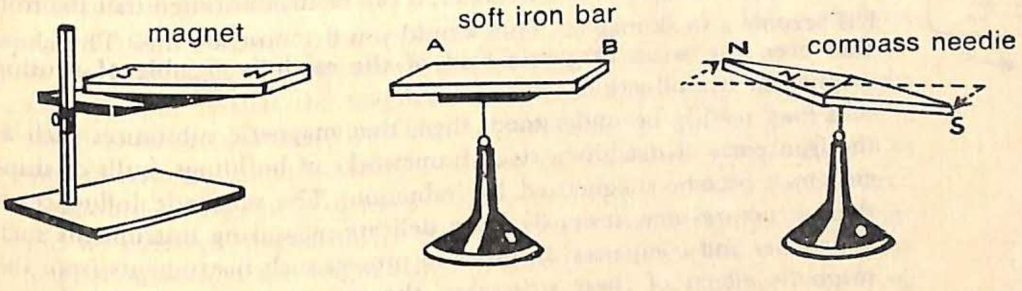


Fig. 14.1 **Magnetic induction**

An unmagnetized iron bar will not attract or repel a compass needle. If, however, we bring a bar magnet near it, the iron bar becomes a magnet. If the north pole of the bar magnet is brought near end A of the iron bar as shown in Fig. 14.1, then the further end B of the iron bar is seen to be a north pole since it repels the north pole of the compass needle. If the bar magnet is now removed the compass needle will no longer be deflected, showing that the iron bar ceases to be a magnet. If the bar magnet is again brought near the iron bar with the south pole near A, the further end B is seen to be a south pole. In each case the iron bar is said to have been *magnetized by induction; the inducing pole induces a similar pole in the further end of the iron bar, and an opposite pole in the near end.* The iron bar loses most of its induced magnetism when the inducing pole is removed. A bar of steel under the same circumstances would not be as strongly magnetized by induction as the iron bar, but would retain more of the induced magnetism than the iron bar does, after the inducing pole is removed.

There is no significant difference in the process if the iron bar is brought into contact with one of the poles of the bar magnet. The magnetization process is somewhat more efficient due to the reduction of the air gap. This is sometimes referred to as *magnetization by contact*. Thus in Fig. 14.2 the magnet induces an opposite pole in the nearer end and a similar pole in the further end of the nail in contact with it. This nail is now a magnet and it induces an opposite pole in the nearer end and a similar pole in the further end of the nail touching it, which thus becomes a magnet, and in turn magnetizes the next nail, and thus the magnet can hold up quite a few nails. What happens when you separate the magnet from the top nail? Why is this? You have studied in Chapter 6 that heating destroys magnetism. What would happen if you heat the second nail from top? Explain why. The attraction of unmagnetized iron by a magnet may be accounted for in terms of magnetic induction. The magnet induces an opposite pole in the nearer end of the iron, and the unlike poles – the induced pole and the inducing pole – attract each other. The attraction between the magnet and the iron is mutual; each attracts the other. When both are floated on corks, either will move under this attraction if the other is held fixed,

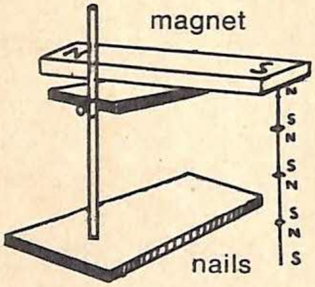


Fig 14.2
A magnet holds up a chain of nails

The dip of a magnet is shown in Fig. 6.7 and the reason for it is explained in Chapter 6, section 3. If a bar of soft iron is held at the angle to the earth's surface that is indicated by a freely suspended dipping magnet, and one end is tapped sharply with a hammer, it can be demonstrated that the iron has become a weak magnet. How would you demonstrate this? This shows that even the weak magnetic field of the earth is capable of causing magnetism by induction.

It may readily be understood, then, that magnetic substances such as the iron parts of machines, steel, frameworks of buildings, hulls of ships etc., may become magnetized by induction. The magnetic influence of these structures may seriously affect delicate measuring instruments such as watches and compasses. In order to protect such instruments from the magnetic effects of these structures, the instruments are enclosed in a *magnetic shield*, such as an iron case. This shield takes all the magnetic effect and prevents any of it from reaching the instruments inside it.

2. The molecular theory of magnetism

We learned in Chapter 6 that every magnet has two poles, a north pole and a south pole, one at each end. If we try to separate these poles by cutting the magnet in half, we find that each half is a complete magnet with a north pole and a south pole of its own. And if we cut each of these in half, we get two more complete magnets from each. This can be repeated again and again with the same results, but in every case (see Fig. 14.3) two new

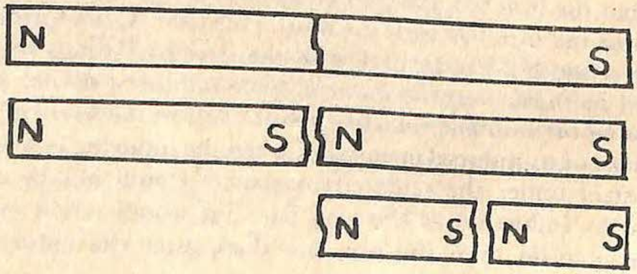
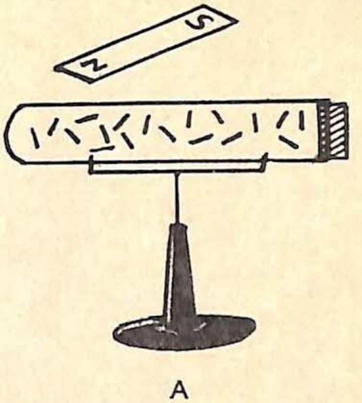
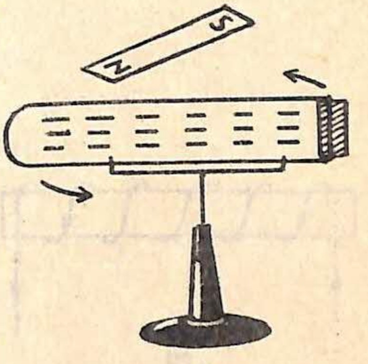


Fig. 14.3 **Breaking a magnet into smaller and smaller magnets**



A

haphazard arrangement
unmagnetized state



B

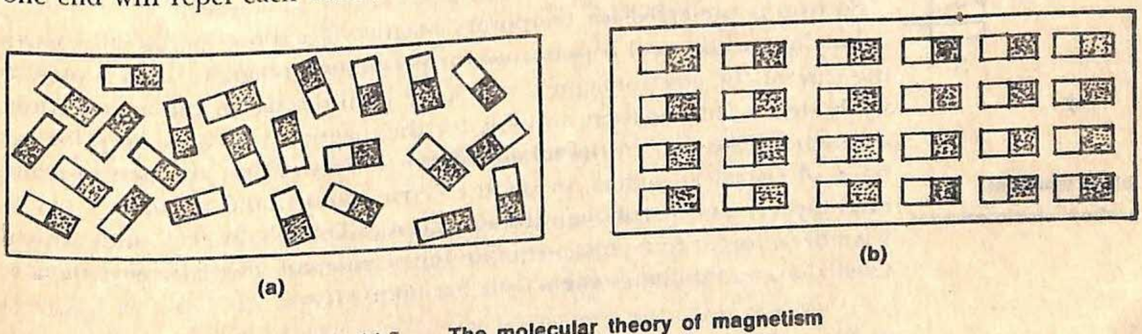
straight line alignment
magnetized state

Fig. 14.4

A test tube containing iron filings
(a) unmagnetized (b) magnetized

magnetic poles appear at the middle, where no poles existed before. This seems to indicate that magnetic poles exist in pairs, and one cannot be isolated from the other. It also shows that a large magnet is made up of a number of smaller magnets. This, if true, means that we should be able to make a large magnet by putting smaller magnets together. Half-fill a test tube (see Fig. 14.4(a)) with unmagnetized iron filings distributed uniformly in depth and magnetize it by any of the methods explained in Chapter 6, section 2. Each of the iron filings now becomes magnetized, and all the iron filings arrange themselves as shown in Fig. 14.4(b). The test tube filled with iron filings now becomes a large magnet consisting of hundreds of small magnets, the individual iron filings. The entire test tube, when the iron filings are in the orderly arrangement shown in Fig. 14.4(b), behaves as a magnet, and its ends can be attracted or repelled by the poles of another magnet.

From the preceding discussion we see that a magnet acts as if it is made up of a number of very tiny magnets. The tiniest possible magnet is likely to be the smallest particle into which the magnetic substance can be broken and still retain its identity. This particle, as we have learned, is the molecule of the substance.



(b)

(a)

Fig. 14.5 **The molecular theory of magnetism**

Evidently then, when iron is magnetized, the molecules of iron behave as the iron filings in the above experiment. Magnetism is not created; what is done is that the magnet molecules are arranged in an orderly manner. In the unmagnetized state, the millions of magnet molecules in the substance are haphazardly arranged as shown in Fig. 14.5(a). The haphazard arrangement of north and south poles neutralizes their effect, and no external magnetism is evident. In the magnetized state, all the magnet molecules are aligned in an orderly arrangement, with all the north poles pointing towards one end, and all the south poles pointing towards the other end, as shown in Fig. 14.5(b). One end shows a north polarity and the other end shows a south polarity. In the middle region of the bar the north and south poles of the molecule magnets neutralize each other, and this accounts for the concentration of magnetic properties at the poles of the magnet. It should be noted that the free north poles at one end will repel each other, and will therefore spread apart. Similarly the free south poles at the other end, due to their mutual repulsion, also fan out. Fig. 14.5(b) suggests the ideal straight line alignment of the magnet molecules. Draw a diagram to show the actual positions of the molecules at the ends of the magnet. Does the diagram you have drawn explain why the iron filings in Fig. 6.2 on p 55 are spread over the ends of the bar magnet i.e. why the poles spread over and around each end?

This theory of magnetism provides a simple explanation of many magnetic phenomena. The fact that there are the same numbers of unbalanced north and south poles at either end of a magnetized iron bar means that the poles of a bar magnet are of equal strength. It also explains why equal and opposite poles will be produced on dividing and subdividing the magnet. When all the molecule magnets have been drawn into line (see Fig. 14.5(b)) there can be no further increase in magnetic strength, so this theory also explains 'magnetic saturation', i.e. that a magnetic substance can be magnetized only up to a certain strength. The loss of magnetism through rough handling or heating is due to the disturbing of the straight line alignment and a reversion to the haphazard arrangement. Study Fig. 14.1 again. When the north pole of the bar magnet is held near A, it attracts all the south poles of the molecule magnets of the bar AB. These molecule magnets swing into alignment with their south poles pointing towards A, and their north poles pointing towards B. This explains why a south pole is induced at A and a north pole at B.

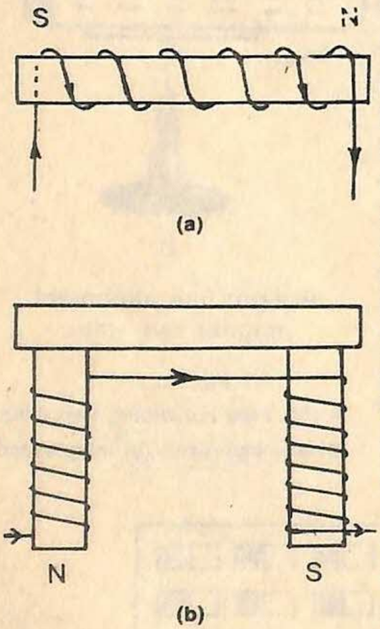


Fig. 14.6

(a) A bar electromagnet

(b) A horseshoe electromagnet

3. Behaviour of soft iron and steel

Take two bars, identical in size and shape, one of iron and the other of steel. Magnetize each equally, either by an equal number of strokes with the same magnet, or by the same current through the same coil. Test the strengths of the magnets so produced. Can you suggest how this could be done? Then put the magnets away and test their strengths the next day, and the day after that. Your results will show that iron is the more strongly magnetized of the two, but that the steel keeps its magnetism longer than the iron does. So we say that iron has a higher *susceptibility* and a lower *retentivity*, and that steel has a lower *susceptibility* and a higher *retentivity*. This is because the molecule magnets of iron, during the process of magnetization, move into the required straight line alignment much faster than those of steel. After magnetization, however, the molecule magnets of iron move out of their straight line alignment much faster than those of steel.

So iron is preferred for temporary magnets i.e. those for use at a particular time, while steel is preferred for permanent magnets. Iron is used as the core of the electromagnets which we shall discuss in the next section, while steel would be more suitable for the magnets which we keep for use throughout the year in the laboratory, or for those that are used in many types of electrical meters, in small electric motors, and in many types of loud-speaker and earphone. Modern alloys like 'cobalt steel' and 'alnico' have been found to be most suitable for permanent magnets; once magnetized they retain their magnetism for many years.

4. Electromagnets and their applications

In Chapter 6, Fig. 6.4 we saw that if an electric current is passed around a magnetic substance it will be magnetized. If the substance is iron it will be magnetized very quickly, immediately as the current is switched on, and will lose its magnetism as soon as the current is switched off. How would steel, permalloy or alnico behave?

A soft iron *core* around which a coil is wound is called an *electromagnet*. It may be either of the bar type shown in Fig. 14.6(a), or the horseshoe type shown in Fig. 14.6(b). In either case the polarity of each end is determined by the rule stated in section 2, Chapter 6. Study this rule again, and apply it to each case of Fig. 14.6 and check that the polarities are as stated.

Electromagnets have a great variety of uses ranging from providing essential parts of electric motors, such as are used to drive electric tramcars and trains, as well as for providing the lifting power of huge cranes which unload cargo from ships. Here we shall describe two applications of the electromagnet; the electric bell, and the relay switch.

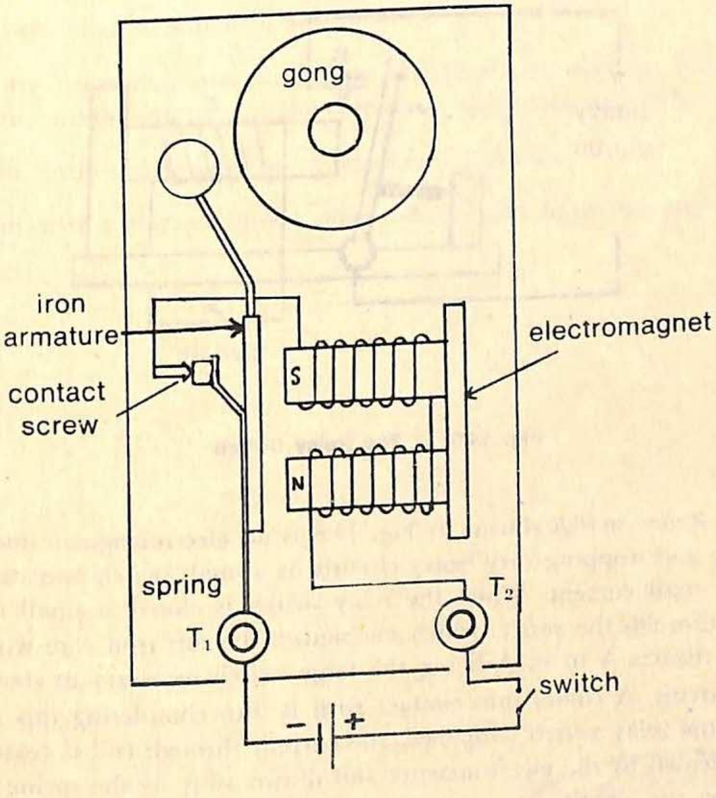


Fig. 14.7 **The Electric Bell**

The Electric Bell consists of a gong, a horseshoe electromagnet, an easily magnetized soft iron bar called the *armature*, and a contact screw arranged as shown in Fig. 14.7. When the switch is closed current flows through the coil wound around the electromagnet, causing the armature to be attracted to it, and the gong to be struck. As the armature moves away from the contact screw, the circuit is broken. The electromagnet loses its magnetism and no longer attracts the armature, which is pulled back by the spring action. As the armature touches the contact screw the circuit is again completed, and the cycle is repeated and the gong is struck again.

Thus there will be a continuous ringing as long as the switch is closed, due to the continuous 'make-and-break' of the circuit, as the armature returns to and is pulled away from the contact screw.

The electric bell is sold as a complete unit and is connected up by joining its terminals T_1 and T_2 to the local battery, or cell, and switch. Sometimes the switch is provided with the unit.

It is not very difficult to make an electric bell, improvising the parts e.g. a nail or screw for the contact screw, an old bicycle bell gong, copper wire winding etc., and the more mechanical-minded and inventive of you should have no difficulty making one which works well.

The Relay Switch

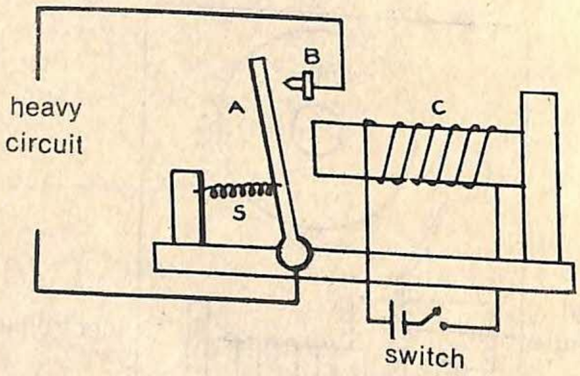


Fig. 14.8 **The Relay Switch**

The Relay Switch shown in Fig. 14.8 is an electromagnetic means of starting and stopping very heavy circuits by a small switch operated with a very small current. When the relay switch is closed, a small current passes through the coil C which magnetizes the soft iron core within it, which attracts A to it, A being the large switch necessary to start some large circuit. A comes into contact with B thus completing this circuit. When the relay switch is opened, the current through coil C ceases, and A is released by the electromagnet and drawn away by the spring S thus breaking the circuit.

A single operator, using a panel of such relay switches, can start or stop any single one of a large complex of heavy circuits by just pressing a button.

Using a relay switch a tiny current may cause a ship to be launched.

The manual (or keyboard) of an electrically operated pipe organ is arranged so that each of the keys operates a relay which controls the circuit admitting air into a particular pipe emitting a particular note.

The automatic signals on the electric railway make use of relays. Relays are also used as 'cut-outs', which are devices for automatically stopping a current when it exceeds a certain safe value.

Questions

1 Describe an experiment to illustrate magnetic induction. What poles would be induced in the near and far ends of a body by an inducing South pole?

2 Explain the molecular ('little magnets') theory of magnetism, and use it to explain:
  - a magnetization and demagnetization (e.g. by rough handling or heating).
  - b equality of strength of the two poles of a magnet.
  - c magnetic saturation.
  - d magnetic induction.
  - e the behaviour of soft iron and of steel.

3 What are electromagnets? State three uses of electromagnets. What substance would you use for the core of an electromagnet? Why?

4 Explain, with a diagram, how an electric bell works.

5 Explain, with a diagram, how a relay switch works. State two uses of relays.

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More About Electricity

1. Potential Difference, Current and Resistance: Ohm's Law.

In Chapter 7, section 3, we learned that an electric current was a moving stream of electrons. Just as a stream of water would only flow from A to B if the pressure at A was greater than the pressure at B, so also electrons would only flow from P to Q if there was a greater concentration of electrons at P than at Q (see Fig. 7.4). Electrons, as we have learned, carry a negative charge. A surplus of electrons at P creates what is termed a *negative potential*. A deficit of electrons means a shortage of negative charges and therefore a *positive potential*. We know that like charges repel each other, so the mutual repulsion of electrons will cause them to move from where there is an excess of them towards where there is a deficit of them i.e. the electrons due to their mutual repulsion move from negative potential to positive potential. Now the word 'negative', mathematically, means less than zero, while 'positive' means greater than zero. Therefore positive is greater than negative. We have seen that movement is always from higher to lower pressure; fluids move from higher to lower pressure, and heat flows from the body at the higher temperature to that at the lower temperature. To keep the same convention we say that an electric current moves from higher to lower potential i.e. from positive to negative potential. Thus the direction of the electric current is opposite to the direction of the electron flow causing it. Now, still referring to Fig. 7.4, we saw that if the difference in pressure between A and B was great, the movement of water from A to B would be faster, while if there was little difference in the heights of the columns of water above A and B; i.e. if there was little difference in pressure between A and B, the rate of flow from A to B would be slow. Rate of flow is termed *current*, so the current flowing from A to B will vary in magnitude with the magnitude of the difference in pressure, i.e. the difference in height of water column above, at A and B. Similarly the rate of flow of electrons from P to Q (or the magnitude of the current flowing from Q to P) would vary with, or, is directly proportional to, the difference in concentration of electrons at P and Q. This difference is called the difference in potential, or *potential difference*, between Q and P.

Thus we conclude that the flow of current along a conductor is directly proportional to the potential difference across the ends of the conductor. Now if two quantities are directly proportional, their ratio remains constant as they change. Thus if one is doubled, the other will be doubled, etc. So we see that

$$\frac{\text{potential difference across the ends of a conductor}}{\text{current flowing in the conductor}} = \text{a constant}$$

This constant depends on the nature of the conductor, and is greater for poor conductors and less for good conductors. It is in fact the resistance that particular conductor offers to the flow of electrons through it. Abbreviating 'potential difference' as p.d., we may now write the above equation as

$$\frac{\text{p.d. across the ends of a conductor}}{\text{current flowing through the conductor}} = \text{resistance of the conductor.}$$

The resistance of a conductor, as you will learn later, changes with its temperature, and so a complete statement of all we have discussed above would be: '*The current flowing in a conductor is directly proportional to the potential difference across the ends of the conductor, temperature remaining constant.*' This relationship was established by Georg Simon Ohm, so this statement is known as *Ohm's Law*.

Potential difference is measured in *volts* and is denoted by the letter 'V', current is measured in *amperes* and is denoted by the letter 'I', and resistance is measured in *ohms* and is denoted by the letter 'R'. Thus the equation written above can be represented briefly as

$$\frac{V}{I} = R \text{ or } V = IR \text{ or } I = \frac{V}{R}$$

where V is in volts (abbreviated V), I is in amperes (abbreviated A), and R is in ohms (abbreviated Ω, which is the Greek letter 'omega').

Illustrative examples

1. A piece of wire has a resistance 10 Ω. What p.d. must be maintained across its ends so that a current of 2A will flow along it?

   Answer: $V = IR = 2 \times 10 = 20$ V.

2. A p.d. of 12V connected across the ends of a wire causes a current of 1.5A to flow through it. Calculate the resistance of the wire.

   Answer: $R = \frac{V}{I} = \frac{12}{1.5} = 8\ \Omega.$

3. The bar of an electric heater has a resistance of 500 Ω. What current will flow through it when it is connected to the mains supply of 220 V?

   Answer: $I = \frac{V}{R} = \frac{220}{500} = 0.44$ A.

We have learned above that a current will flow through a conductor only as long as a difference in potential, or a p.d. is maintained across its ends. We shall now study two ways in which such a p.d. can be maintained. The first is by using chemical energy as in the simple cell, and the second is by using mechanical energy as in the case of electromagnetic induction.

2. The simple cell

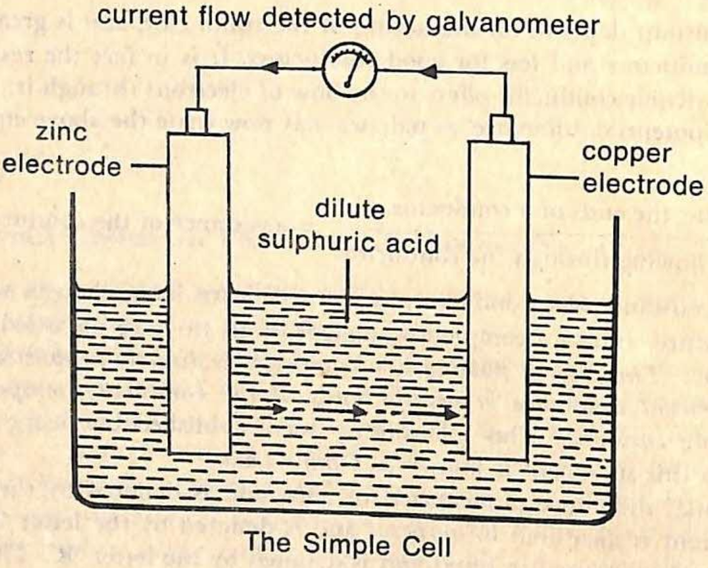

Fig. 15.1 **The Simple Cell**

The simple cell shown in Fig. 15.1, consists of a zinc rod or strip, called the zinc electrode, and a copper rod or strip, called the copper electrode, dipping into dilute sulphuric acid. The dilute sulphuric acid is the chemical H_2SO_4 mixed with water. The sulphuric acid is called an *electrolyte*, which means it is a liquid which can conduct electricity (i.e. allow the movement of electrons) along itself because of the presence of *ions* in it. We studied in Chapter 7, section 2, that every atom contains, in the uncharged state, an equal number of protons and electrons. This is also true of a group of atoms, or a *radical* as such a group is called, such as the SO_4 radical. Now when an atom or a group of atoms (i.e. a radical) gains or loses electrons it acquires a positive or a negative charge, and becomes an 'ion'. Thus when Zn, which represents a zinc atom, loses two electrons it becomes Zn^{2+} which is a zinc ion carrying a positive charge of strength 2.

$$\text{Thus } Zn - 2e \longrightarrow Zn^{2+}$$

The positive charge occurs because there will now be two more protons than there are electrons, since the atom has lost two electrons. In the uncharged state the zinc atom has 30 protons and 30 electrons; after losing 2 electrons it has 30 protons and 28 electrons. Now 28 electrons can balance the charge on 28 protons, and so there is the unbalanced charge on two protons which gives the zinc ion its positive charge of strength 2. A chlorine atom has 17 protons and 17 electrons. If it were to gain one more electron it would have 17 protons and 18 electrons. The 17 protons could only balance the charge on 17 electrons, and so there will be one electron whose charge will remain unbalanced giving the ion a single negative charge, i.e.

$$\underset{\text{(chlorine atom)}}{Cl} + \underset{\text{(electron)}}{e} \longrightarrow \underset{\text{(chlorine ion).}}{Cl^{-}}$$

Similarly we have:

$$\underset{\text{(sulphate radical)}}{-SO_4} + \underset{\text{(two electrons)}}{2e} \longrightarrow \underset{\text{(sulphate ion)}}{SO_4^{2-}}$$

$$\underset{\text{(hydrogen atom)}}{H} - \underset{\text{(electron)}}{e} \longrightarrow \underset{\text{(hydrogen ion)}}{H^{+}}$$

$$\underset{\text{(copper atom)}}{Cu} - \underset{\text{(two electrons)}}{2e} \longrightarrow \underset{\text{(copper ion)}}{Cu^{2+}}$$

We are now in a position to explain how the simple cell maintains a constant difference in potential, i.e. a difference in concentration of electrons, across its electrodes.

The sulphuric acid, H_2SO_4, produces H^{+} ions and SO_4^{2-} ions, as represented by the ionic equation

$$H_2SO_4 \longrightarrow H^{+} + H^{+} + SO_4^{2-}$$

Note that there is an ionic equilibrium i.e. an equal number of positive and negative charges on the ions produced. The water which dilutes the sulphuric acid produces ions according to the equation

$$H_2O \longrightarrow H^{+} + \underset{\text{(hydroxyl ion)}}{OH^{-}}$$

but the water produces so few of these ions that their presence may be ignored for the purpose of our present discussion.

The zinc atoms present in the zinc electrode become zinc ions. To become a zinc ion each zinc atom, as we saw above, must lose two electrons. The zinc atoms, each leaving behind 2 electrons on the zinc electrode, enter the solution as zinc ions. Hence the zinc electrode keeps gaining electrons, two from each zinc atom which ionises, and so gains a surplus of electrons i.e. a negative potential.

Meanwhile the ionic equilibrium of the solution has been upset by the entry of the zinc ions as there are now more positive charges than negative charges among the ions in the solution. This requires that some positive ions leave the solution. Hydrogen being lower than zinc in the *electro-chemical series* (of which you will learn more later), the hydrogen ions must leave the solution i.e. can no longer remain as ions in it. They must therefore lose their positive charge, and each ion can only do this by the gain of an electron. The copper electrode provides them with these electrons. The H^{+} ions turn into H atoms by gaining electrons from the copper electrode

$$H^{+} + e \longrightarrow H.$$

These H atoms combine to form H_2 molecules, and bubbles of hydrogen gas are seen at the copper electrode.

The copper electrode in losing electrons to the hydrogen ions develops a deficit of electrons i.e. a positive potential. If a wire connects the zinc electrode to the copper electrode, electrons will flow along this wire from the zinc to the copper i.e. a current will flow in the direction of the arrow shown in the figure, and will keep on flowing as long as the difference in potential is maintained between the two electrodes as explained above. A sensitive instrument for detecting current will show the presence of this current by a deflection of its pointer.

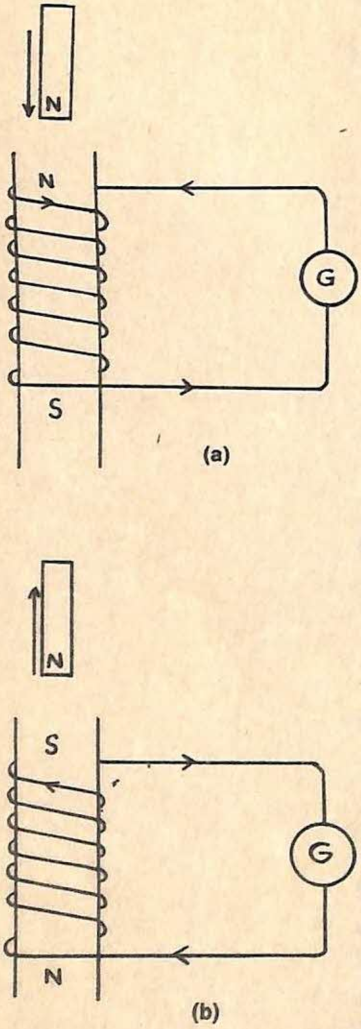

Fig. 15.2 **Electromagnetic induction**

3. Electromagnetic induction

Fig. 15.2 shows a coil of wire connected to a sensitive galvanometer, an instrument for detecting current. Since there is no current flowing in the coil, there will be no deflection of the pointer. If a magnet is moved into the coil (see Fig. 15.2(a)), the galvanometer needle (or pointer) will be deflected for as long as the magnet is being moved. If, as shown in Fig. 15.2(b), the magnet is now withdrawn from the coil, the galvanometer needle will be deflected in the opposite direction, but only for as long as the magnet is being moved. Repeat the experiment, pushing the magnet into the coil, and withdrawing it, at different speeds, and note the amount of deflection of the galvanometer needle, which indicates the strength of the current produced, in each case. You will see that faster movements of the magnet into or out of the coil produce greater currents, in one direction or the other.

Repeat the experiment with a stronger magnet, and then again with a weaker one. You will see that stronger magnets will produce stronger currents.

Since a current flows in the wire while the magnet moves into or out of the coil, this means that a p.d. is being created across the ends of the coil. It should also be realised that it is the relative movement of the two which produces this p.d. i.e. that a p.d. would be produced if the magnet were held still and the coil was moved around it and then away from it: This is the principle of the generator, in which electrical energy is generated by rotating a coil between the north and south poles of a magnet.

The phenomenon described above whereby p.d., and therefore current, is produced by the relative movement of magnet and coil, is called *electromagnetic induction*, and the current produced is called an *induced current*.

Questions

1 What condition is necessary across the ends of a conductor if a current is to flow in it? State Ohm's Law. Why is it necessary to include a condition about temperature in the statement of Ohm's Law?

2 In what units are p.d., current and resistance measured? State the relationship between them in the form of an equation.

3 What is the resistance of a torch bulb that carries a current of 0.5A when connected to a 6-volt battery?

4 The resistance of a conductor is 25 Ω and it carries a current of 8.5A. What is the potential difference across its ends?

5 How much current does a 44-ohm resistance draw when operated on 220-volt mains?

6 What is an 'ion'? What is an 'electrolyte'? Give one example of each. The atom of copper has 29 protons and 29 electrons. The atom of bromine has 35 protons and 35 electrons. The copper ion is represented by Cu^{2+} The bromine atom ionises by gaining an electron. Use the above information to answer the following questions:

- a How many protons and how many electrons are there in a copper ion?
- b Write an equation to represent the conversion of a copper atom to a copper ion.
- c By what symbol would you represent a bromine ion?
- d Write an equation to represent the change of a bromine atom to a bromine ion.
- e How many protons and how many electrons are there in a bromine ion?
- f Write an equation to represent the discharge of a copper ion into a copper atom.
- g Write an equation to represent the discharge of a bromine ion into a bromine atom.

7 Explain the ionic changes which take place in a simple cell and how these maintain a constant p.d. across the electrodes of the cell. In what direction is (a) the electron flow, (b) the current flow,

(i) in a wire connecting the zinc and copper electrodes,

(ii) through the electrolyte viz. the dilute sulphuric acid?

Note that there are four questions in this paragraph.

8 Describe, with the help of a labelled diagram, an experiment by which an electric current is produced by electromagnetic induction. Explain clearly two factors on which the strength of the induced current depends.

What type of energy is expended, and what type of energy is produced, during electromagnetic induction?

Answers to Questions

Chapter 5

(p. 47)

1. 4 m 2. 20 gf vertically upwards

(p. 53)

11. 2 m 12. 20 g 14. 20 J

Chapter 8

(pp. 87-90)

4. (a) 130 N bisecting the angle between them.

5. 36 N making an angle of 146° with the 30 N force and an angle of 124° with the 20 N force.

6. (a) 4 newton metres (b) 4 newton metres (c) 120 newton metres

7. (a) 75 N (b) 8 N

8. (a) 30 m (b) 4 m

9. 210 N

10. 60 kgf cm; 60 kgf cm; 1.5 kg; 2.5 kgf or 24.5 N vertically upward.

12. 50 cm; to the right.

14. 14 km in a direction 093°.

15. 506 km/hr 108° i.e. 18° south of east

16. between 071° and 072° (071°36′)

17. 78.5 m/s^2

18. 68.6 m/s

19. 16 s

20. 1 m/s^2

22. (a) 98 J (b) 4 J (c) 1960 J

28. (a) 16 times (b) 8 times (c) twice (d) twice (e) 5 times.

29. (a) becomes one-quarter of what it was
(b) becomes four times greater.

Chapter 9

(pp. 101-102)

4. 91 cm^3

5. 200 litres.

6. 1 050 gf/cm^2 or 10 500 kgf/m^2; 3 500 gf or 3.5 kgf.
12. 25 gf/cm^2; 25 kgf; 2 kgf.

Chapter 10

(p. 106)

1. (a) 15 g (b) 17 g
2. (a) 1.075 kg (b) 1.11 kg
3. (a) 1 gf (b) 1 cm^3 (c) 1 cm^3 (d) 6 g/cm^3; 1.02 g/cm^3; 5.6 gf
4. 50 cm^3 (a) 368.5 gf (b) 363.5 gf
5. (a) 10 cm^3 (b) 8.9 g/cm^3 (c) 0.8 g/cm^3

(p. 107)

1. (a) 20 cm^3 (b) 2.5 g/cm^3 (c) 0.87 g/cm^3
2. 10 cm^3; 11.37 g/cm^3; 1.26 g/cm^3

(pp. 113-114)

7. 5 cm^3; 11.3 g/cm^3; 52.5 gf
8. (a) 10 cm^3; (b) 7.9 g/cm^3; (c) 0.7 g/cm^3
9. 20.9 cm^3; 3.21 g/cm^3
10. (a) 20 gf (b) 0.8 g/cm^3
11. 26 gf
12. 40 000 kgf; 9 000 kgf

Chapter 11

(pp. 128-129)

3. (a) 12 600 J (b) 20°C
4. $x = 50$
5. (i) 4.6 J or 1.1 cal (ii) 33.4 J or 8 cal (iii) 210 J or 50 cal
6. (i) 80 g (ii) 11 088 J or 2 640 cal (iii) 24 000 s
   (iv) 0.46 J/g deg C or 0.11 cal/g deg C
7. 0.88 J/g deg C or 0.21 cal/g deg C
8. 8 000 000 calories or 8 000 Calories
9. 12.5 g

Chapter 15

(p. 173)

3. 12 Ω
4. 212.5 V
5. 5A

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